Published in final edited form as:

Popul Environ. 2016 June ; 37(4): 449–463. doi:10.1007/s11111-015-0250-7.

Population recovery in New Orleans after Hurricane Katrina: Exploring the potential role of stage migration in migration systems

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Abstract

In this research brief, we explore how places affected by natural disasters recover their populations through indirect, or “stage,” migration. Specifically, we consider the idea that post-disaster impediments (e.g., housing and property damage) in disaster-affected areas spawn migration flows toward and, over time, to disaster-affected areas through intermediary destinations. Taking as our case Orleans Parish over a five-year period after Hurricane Katrina, we show that stage migration accounted for up to about one-fourth of population recovery. We close by discussing the implications, limitations, and potential extensions of our work.

Keywords

Stage migration; Migration systems; Population recovery; Disasters; Hurricane Katrina

Introduction and Background

Most places exposed to natural hazard events that displace populations recover their losses and even experience population growth (Vale and Campanella 2005). In the case of Orleans Parish¹, as we show in Figure 1, after Hurricane Katrina made landfall on August 29, 2005, the population fell from 494,294 persons in July of that year to 230,172 persons by July of 2006 (U.S. Census Bureau 2011, 2014). Due primarily to positive net-migration, Orleans Parish added residents each year after 2006, reaching 384,320 persons by July of 2014, about three-quarters of its pre-Katrina size. However, as Figure 1 also makes clear,

¹Orleans Parish and the City of New Orleans refer to the same place. Hereafter, for consistency, we use the former. Parishes in Louisiana are equivalent to U.S. counties.

population recovery in Orleans Parish was uneven in the years following Hurricane Katrina. Of the 154,148 residents gained between 2006 and 2014, only about one-fourth were recovered between 2006 and 2007, with diminishing population recovery each year thereafter. The slow pace of population recovery was due, in part, to delayed migration to Orleans Parish on account of post-disaster “impediments” that included extensive damage to residential and non-residential property and structures, slow and inadequate dispersal of recovery funds, employment layoffs due to contractions in demand for goods and services, inadequate repairs and improvements to existing levees, and debilitated healthcare, school and emergency services (Green et al. 2007:311; see also Elliott 2014; Finch et al. 2010; Fussell 2015; Fussell et al. 2014; Kamel 2012; Plyer and Ortiz 2011; Wang et al. 2014), not to mention the politically and emotionally charged context in which restoration and recovery efforts unfolded (Colten et al 2008; Kates et al. 2006; Olshansky et al 2008).

However, despite the fact that migration to Orleans Parish was impeded after Hurricane Katrina, existing research has yet to consider another complimentary possibility: the potential for indirect migration towards Orleans Parish through one or more intermediary destinations, and, over time, to Orleans Parish as a source of population recovery. Places are connected to one another by migration flows in what is sometimes referred to as a migration system (Mabogunje 1970; Plane and Rogerson 1986; Zlotnik 1992). Because of this, it follows that places are potentially indirectly connected to one another via intermediary destinations (Conway 1980; Plane et al. 2005). This transitivity raises the prospect that if migration is delayed by impediments in a disaster-affected area like Orleans Parish, one possible response of the migration system might be to redirect flows toward and, at some later point in time when conditions permit, to the disaster-affect area through one or more intermediary destinations. To date, studies have only gone so far as to show that places directly connected to a disaster-affected area by migration flows before a disaster are implicated, as key migrant-sending areas, in the ability of the disaster-affected area to recover its population (Curtis et al. 2015; Fussell et al. 2014).

Although indirect migration has not been examined in research on migration to and population recovery in disaster-affected areas, it is a foundational migration concept referred to as “stage” migration. Originally, stage migration was coined to characterize place-to-place migration flows “*towards...*major urban centers” through intermediary destinations (Conway 1980:7, emphasis ours; see also Hägerstrand 1957; Skeldon 1977). Most recently, Plane et al. (2005:15314) invoked the idea of stage migration to examine place-to-place migration flows across a “hierarchy” of metropolitan and micropolitan areas in the United States using data similar to those used in the current paper (discussed in the next section).

We focus on stage migration as an aggregate-level process of migration flows between places through one or more intermediary destinations and the implications for population recovery in disaster-affected areas. However, it is important to note that these aggregate-level flows are the product of the migration decisions and behaviors of actors (e.g., individuals and households) (Bakewell 2013; Conway 1980). In a short-term cost-benefit migration framework (Greenwood 1995; McCarthy et al. 2006; Sjaastad 1962), impediments in a disaster-affected area, of the sort described above, might represent costs that are too great for actors to incur, thereby preventing migration to the disaster-affected area. At the same time,

the costs of migrating to an intermediary destination might be considerably lower. Actors might migrate to one or more intermediary destinations because these places provide more suitable and affordable housing (Fussell and Harris 2014), are nearer to family and friends (Chamlee-Wright and Storr 2009), or are closer to the disaster-affected area itself, which is advantageous when repairing and rebuilding homes and other property that were damaged or destroyed (Sastry and Gregory 2014). Additionally, indirect migration might provide opportunities for actors living outside of a disaster-affected area and who did not experience the disaster to capitalize on employment opportunities in the recovery economy (e.g., in construction) by relocating nearby, and perhaps eventually to, the disaster-affected area for work (Ehrenfrucht and Nelson 2012; Fussell 2009; Green et al. 2007).

The varied migration decisions and behaviors of actors are observed in the aggregate as stage migration flows between places (Conway 1980), which, we argue, might play a role in the population recovery of disaster-affected areas. As we discuss in detail in the next section, data limitations ultimately prevent direct assessments of stage migration as a source of population recovery in disaster-affected areas like Orleans Parish after Hurricane Katrina. Accordingly, we use what data are available—specifically, annual county-to-county migration flow data from the Internal Revenue Service (IRS)—to explore, in synthetic fashion, the *potential* role of stage migration as a source of population recovery in Orleans Parish. The primary drawback of our approach is that, as Conway (1980:10) noted, we effectively document “all possible” stage migration flows to Orleans Parish, such that our estimates represent upper bounds. Of course, the primary benefit of our approach is that we consider and document the potential role of stage migration as a source of population recovery in Orleans Parish, which is important given the small, but growing, body of research on the relationship between environment (disasters, climate change, etc.) and human migration (McLeman 2014).

Approach

Definition of Stage Migration

We define stage migration as a migration flow from sending area i to receiving area j that involves one or more intermediary destinations k , such that $i \rightarrow j \rightarrow k$. For a single time interval t to $t+n$, where t is the start of the post-disaster period, and, for ease of notation, we simply write this time interval as t , stage migration between sending area i and receiving area j is not possible because only one time interval has elapsed since the start of the post-disaster period. We might write this flow as m_t^{ij} . However, over two time intervals, t to $t+n$ and $t+n$ to $t+2n$, stage migration between sending area i and receiving area j is possible, and, moreover, can involve one, and only one, intermediary destination. We might write this flow as $m_{t,t+n}^{ij,s}$, where s refers to stage migration. Over three time intervals, stage migration between sending area i and receiving area j potentially involves two intermediary destinations, written in the following way, $m_{t,t+2n}^{ij,s}$. As is evident, $m_{t,t+n}^{ij,s}$ and $m_{t,t+2n}^{ij,s}$ are not directly comparable because they potentially encompass different numbers of stages, and therefore summarize stage migration over different lengths of time in the post-disaster period.

Longitudinal Versus Synthetic Flow Data

Ideally, stage migration to Orleans Parish is measured as follows (Conway 1980). At the start of the post-disaster period—in our case, in 2006—one identifies all actors (e.g., individuals and households) living outside of Orleans Parish. Assuming a one-year measurement interval (i.e., actors are counted as migrants if they migrate at least once in a given year) and given our definition of stage migration, there can be no stage migration to Orleans Parish between 2006 and 2007. Instead, actors can either remain in their current county of residence or migrate directly to another county, including Orleans Parish. However, between 2006 and 2008, one can identify stage migrants to Orleans Parish by comparing each actor's place of residence in 2006 to 2008. If their place of residence in 2008 is Orleans Parish *and* their place of residence in 2007 differs from those in 2006 and 2008, then the sum of these actors comprise the stage migration flow to Orleans Parish between 2006 and 2008. This process can be repeated for subsequent years to measure stage migration flows to Orleans Parish over, for example, the 2006–2009 and 2006–2010 periods.

As is evident, the ideal measurement of stage migration to Orleans Parish requires, first and foremost, longitudinal data on actors' migration patterns, with dates and locations of each change of residence. Using our definition above, stage migrants are identified, and the stage migration flow is measured as the sum of actors who, over time, migrate to Orleans Parish through one or more intermediary destinations. In practice, however, we lack complete longitudinal data on actors' migration patterns that would allow us to directly measure stage migration to Orleans Parish after Hurricane Katrina. Accordingly, taking a more synthetic approach, we explore the *potential* for stage migration to Orleans Parish using county-to-county migration flow data from the IRS (Gross 2005). While these data afford the opportunity to analyze the entire U.S. migration system of county-to-county flows (Curtis et al. 2015; Fussell et al. 2014), as we show in Figure 2, they do not perfectly align with the ideal data, described above, because the IRS data do not afford the ability to observe actor's longitudinal migration patterns.

In Figure 2, suppose that we are concerned with the stage migration flow from county i to county j through the intermediary destination of county k . As shown in Panel A, ideally, we have information on the number of actors who migrated (i.e., the size of the flow) from county i to county k in a given time interval t , m_t^{ik} , and on the subset of actors from i who, in the next time interval $t+n$, migrated to j from county k , $m_{t+n}^{kj,i}$. While the IRS data provide the first count, as we show in Panel B, the second count is rolled into a more general count of *all* migrants from county k to county j , m_{t+n}^{kj} . As we noted earlier, this means that our estimates of stage migration are upper bounds because they capture “all possible” stage migration to Orleans Parish based on observed county-to-county migration flows over time (Conway 1980:10). Put differently, as we describe further in the next subsection, our estimates effectively summarize the stage migration that would result if persons migrated indirectly through intermediary destinations according to the observed probabilities of county-to-county migration in the IRS data.

The IRS migration data are reported in the form of counts of county-to-county migration flows of tax filers and their dependents between all counties in the United States. To

generate these counts, the IRS matched tax returns in consecutive years and noted whether the tax-filing addresses matched; thus, these counts capture changes in county residential status by tax-filers (roughly equivalent to households) and tax exemptions (roughly equivalent to individuals). Following prior research (Curtis et al. 2015; Fussell et al. 2014; Vachon 2014), we focus our analysis on the tax-filer set of household migration flows given that migration is frequently a household-level strategy in response to livelihood uncertainty and risk (Stark and Bloom 1985).

Because the IRS data are derived from tax returns, they underrepresent those who do not file, most notably the poor, the elderly and anyone without a social security number, such as immigrants who are not authorized to work in the United States (Gross 2005). That said, a recent study by Molloy et al. (2011) using data from the Current Population Survey (CPS) showed that about 87 percent of household heads in the United States file tax returns annually, thereby providing strong evidence that these data are suitable for analyzing population-level trends (see also Engels and Healy 1981; Isserman et al. 1982). This point is particularly important when one considers that there exist no comparable data on county-to-county migration flows spanning the periods before and after Hurricane Katrina.²

While the IRS data are available annually, Johnson et al. (2008) showed that IRS match rates declined in Orleans Parish and in surrounding parishes between 2005 and 2006 due to absent and late tax filings.³ We therefore exclude the IRS data for 2005, and focus our analysis on the post-Katrina period (2006–2010), with 2010 being the most recent year for which comparable migration data are available from the IRS (Pierce 2015).⁴ We likewise compare migration during this period to migration that occurred before Hurricane Katrina, as we elaborate in the next subsection.

Estimation of Stage Migration using Synthetic Flow Data

In Figures 3 and 4, we illustrate our approach to measuring stage migration flows using a hypothetical example of migration flows between three counties (i , j and k) in three time intervals (1, 2 and 3). We begin, in Figure 3, by displaying three matrices ($\mathbf{M}(1)$, $\mathbf{M}(2)$ and $\mathbf{M}(3)$) containing counts of migrant and non-migrant households. Three matrices ($\mathbf{P}(1)$, $\mathbf{P}(2)$ and $\mathbf{P}(3)$) containing the corresponding transition probabilities are also displayed.

In each matrix, sending counties are listed as rows, and receiving counties are listed as columns. Thus, in the first time interval, of the 100 households in county i , 45 did not migrate, 15 migrated to county k , and 40 migrated to county j . The corresponding transition probabilities are 0.45, 0.15, and 0.40, respectively. As is evident, over time, the populations in counties i and k declined, while the population in county j increased. For the purposes of this illustration, we might therefore think of county j as a disaster-affected county that is

²Although estimates of county-to-county migration flows produced by the U.S. Census Bureau come close, these are problematic because the timing criteria for identifying migrants changed between the 2000 Decennial Census and the various county-to-county migration flow files in the mid- to late-2000s from American Community Survey (ACS), raising issues of comparability.

³The IRS periodizes their estimates using a two-year window where, for example, for the period 2005–2006, 2005 is the year in which migration occurred and 2006 is the tax-filing year. Hereafter, we refer to each period using the former year, the year in which migration actually occurred.

⁴While county-to-county migration flow data are available from the IRS for 2011 and 2012, “due to the methodological changes between [these and past estimates], the data are not directly comparable” (Pierce 2015:2).

gradually recovering its population over time, with the beginning of the first time interval signifying the start of the post-disaster period. Between times 1 and 3, the population of county j increased from 100 households to 150 households. At the end of the third time interval, the population of county j was 160 households ($160 = 20 + 20 + 120$).

Because the IRS data do not afford the ability to track households' actual county-to-county movements over time, and, instead, only provide aggregated annual snapshots of county-to-county migration, our synthetic approach to measuring stage migration utilizes the transition probabilities in Figure 3. In doing so, as shown in Figure 4, we begin by calculating the joint probabilities of county-to-county migration for each pair of counties between time 1 and times 2 and 3.

The joint probabilities of county-to-county migration between time 1 and times 2 and 3 are contained in the $\mathbf{P}(1-2)$ and $\mathbf{P}(1-3)$ matrices, respectively, where:

$$\mathbf{P}(1-2) = \mathbf{P}(1)\mathbf{P}(2) \quad (1)$$

$$\mathbf{P}(1-3) = \mathbf{P}(1)\mathbf{P}(2)\mathbf{P}(3) \quad (2)$$

Next, we display the number of migrant and non-migrant households between time 1 and times 2 and 3. Hereafter, we will refer to these as *cumulative* migration counts. Cumulative migration counts are contained in the $\mathbf{M}(1-2)$ and $\mathbf{M}(1-3)$ matrices, and are calculated by multiplying the size of the starting populations in counties i, j and k at the beginning of the first time interval (100 households in each county, as shown in Figure 3) by the joint probabilities of county-to-county migration in (1) and (2). Thus, for example, we see that, of the 100 households in county i at time 1, 26 households did not migrate between time 1 and time 2, 25 households migrated to county k , and 49 households migrated to county j . The corresponding figures between time 1 and time 3 are 23 households, 24 households, and 53 households, respectively.

We then disaggregate the joint probabilities of county-to-county migration to isolate the stage migration component, or subset, for each pair of counties by applying our earlier definition of stage migration, which was that a migration flow from sending area i to receiving area j is a stage migration flow if it involves one or more intermediary destinations k , such that $i \rightarrow j \rightarrow k$. To illustrate, between time 1 and times 2 and 3, the joint probabilities of migrating from county i to county j are:

$$p_{1,2}^{ij} = p_1^{ii} p_2^{ij} + p_1^{ik} p_2^{kj} + p_1^{ij} p_2^{jj} \quad (3)$$

$$p_{1,3}^{ij} = p_{1,2}^{ii} p_{2,3}^{ij} + p_{1,2}^{ii} p_{2,3}^{ik} p_{3,3}^{kj} + p_{1,2}^{ii} p_{2,3}^{ij} p_{3,3}^{jj} + p_{1,2}^{ik} p_{2,3}^{ki} p_{3,3}^{ij} + p_{1,2}^{ik} p_{2,3}^{kk} p_{3,3}^{kj} + p_{1,2}^{ik} p_{2,3}^{kj} p_{3,3}^{jj} + p_{1,2}^{ij} p_{2,3}^{ji} p_{3,3}^{ij} + p_{1,2}^{ij} p_{2,3}^{jk} p_{3,3}^{kj} + p_{1,2}^{ij} p_{2,3}^{jj} p_{3,3}^{jj}$$

(4)

Applying our definition of stage migration, there is one stage migration pathway from county i to county j in (3) and five stage migration pathways in (4), as indicated by the superscript $.s$.

$$p_{1,2}^{ij.s} = p_{1,2}^{ik} p_{2,2}^{kj} \quad (5)$$

$$p_{1,3}^{ij.s} = p_{1,2}^{ii} p_{2,2}^{ik} p_{3,2}^{kj} + p_{1,2}^{ik} p_{2,2}^{ki} p_{3,2}^{ij} + p_{1,2}^{ik} p_{2,2}^{kk} p_{3,2}^{kj} + p_{1,2}^{ik} p_{2,2}^{kj} p_{3,2}^{jj} + p_{1,2}^{ij} p_{2,2}^{jk} p_{3,2}^{kj} \quad (6)$$

Probabilities of stage migration are displayed for all pairs of counties in the $\mathbf{P}^s(\mathbf{1} - \mathbf{2})$ and $\mathbf{P}^s(\mathbf{1} - \mathbf{3})$ matrices (Figure 4). Given our definition of stage migration, in this example, there can be no stage migration between counties i and j for $i=j$; thus, the main diagonals in the $\mathbf{P}^s(\mathbf{1} - \mathbf{2})$ and $\mathbf{P}^s(\mathbf{1} - \mathbf{3})$ matrices are blank. Subsequently multiplying the size of the populations in counties i , j and k at the beginning of the first time interval by the probabilities of stage migration, we arrive at counts of stage migration flows, $\mathbf{M}^s(\mathbf{1} - \mathbf{2})$ and $\mathbf{M}^s(\mathbf{1} - \mathbf{3})$, between time 1 and times 2 and 3, shown at the bottom of Figure 4. To provide an interpretation, focusing on county j between time 1 and time 2, the cumulative number of households that migrated to j was 98 ($98 = 49 + 49$). Of these 98 households, 10 ($10 = 5 + 5$), or about 10.2 percent ($10.2 = (10 / 98) * 100$), migrated to j via a stage migration pathway involving one intermediary destination. The corresponding figure for stage migration to county j between time 1 and time 3 was 24 ($24 = 12 + 12$) households, or 22.6 percent ($22.6 = (24 / 106) * 100$) of cumulative migration to j .

In this paper, we estimate the size of stage migration flows to Orleans Parish between the start of the post-Katrina period (2006) and each subsequent year (2007, 2008, ..., 2010). Between 2006 and 2007, the number of potential intermediary destinations between a given county in the United States and Orleans Parish is one; whereas, between 2006 and 2010, up to four intermediary destinations are possible.

Going one step further, in order to determine if our estimates of stage migration to Orleans Parish were particularly pronounced as a form of population recovery, and potentially population growth, in Orleans Parish in the post-Katrina period, we compare them to similar estimates for the pre-Katrina period. To generate estimates of stage migration flows in the pre-Katrina period, we use the IRS county-to-county migration flow data in 2004, the year before Hurricane Katrina, to approximate several stage migration processes characterized by different numbers of potential intermediary destinations, and thus lengths of time. In Table 1, we display the joint probability matrices used to estimate cumulative and, ultimately,

stage migration flows to Orleans Parish in the pre-Katrina period. We also provide the corresponding matrices for the post-Katrina period for comparison. These matrices in Table 1 compare to the $\mathbf{P}(1 - 2)$ and $\mathbf{P}(1 - 3)$ matrices shown earlier in Figure 4.

Using information on population size in each U.S. county at the start of the pre- and post-Katrina periods, we use the matrices in Table 1 to derive estimates of stage migration flows to Orleans Parish following the set of steps detailed earlier in (3)–(6).

Results

In Figure 5, we display estimates of total annual, cumulative, and stage migration flows to Orleans Parish in the post-Katrina period to present the full picture of recovery migration. Annual flows to Orleans Parish ranged from a high of 18,408 households in 2006 to a low of 12,799 households in 2010. With respect to cumulative and stage migration flows, it is important to note our use of dashed (versus solid) lines in Figure 5. Dashed lines are used to communicate that the cumulative and stage migration series are not properly time series because each point measures the length of time since 2006, the start of the post-Katrina period, and thereby summarizes cumulative and stage migration to Orleans Parish since 2006. Between 2006 and 2007, a total of 31,044 households migrated to Orleans Parish. By 2010, a total of 55,888 households had migrated to Orleans Parish over the post-Katrina period.

The estimates of cumulative migration are used to generate estimates of potential stage migration to Orleans Parish, as shown earlier in (3)–(6). In Figure 5, stage migration flows comprised a sizeable portion of cumulative migration flows to Orleans Parish over the post-Katrina period. Between 2006 and 2007, stage migration flows to Orleans Parish numbered 3,128 households, accounting for about 10.1 percent of cumulative migration flows. Over the entire post-Katrina period, 2006–2010, some 13,483 households migrated to Orleans Parish via one or more intermediary counties in the United States, accounting for 24.1 percent of cumulative migration flows to Orleans Parish. As we noted earlier, these estimates are upper bounds because they capture all possible stage migration paths that migrants could have followed in migrating to Orleans Parish from other U.S. counties, including, but not limited to, the pathways actually followed, which cannot be distinguished in our (or any existing) data.

In order to determine if our estimates of stage migration were particularly pronounced as a form of population recovery, and ultimately population growth, in Orleans Parish in the post-Katrina period, it is necessary to compare these to similar estimates for the pre-Katrina period. These comparisons, in the form of differences between the pre- and post-Katrina periods, are displayed in Figure 6.⁵ Annual migration flows to Orleans Parish were consistently, but diminishingly, higher in the post- (versus pre-) Katrina period; however, by 2010, migration flows to Orleans Parish were approaching pre-Katrina levels. Cumulative migration flows to Orleans Parish were also elevated in the post- (versus pre-) Katrina

⁵To facilitate a clearer display, the y-axis in Figure 6 has been adjusted so that the maximum value displayed is one-half the maximum value displayed in Figure 5.

period. Between 2006 and 2010, cumulative in-migration flows to Orleans Parish totaled 55,888 households; the corresponding figure for the pre-Katrina period was 38,319 households, for a difference of +17,569 households.

Potential stage migration flows to Orleans Parish were also higher in the post- (versus pre-) Katrina period. Between 2006 and 2007, 3,128 households migrated to Orleans Parish via one intermediary destination, versus 2,346 households in the pre-Katrina period, for a difference of +782 households, or 5.8% of the difference in cumulative migration flows. Over the entire post-Katrina period analyzed in this paper, 13,483 households migrated to Orleans via intermediary destinations between 2006 and 2010, versus 10,361 households in the pre-Katrina period, for a difference of +3,122 households, or 17.8% of the difference in cumulative migration flows. Although, as noted earlier, our estimates are upper bounds, they are positive and, thus, are consistent with the idea of stage migration as a potential source of population recovery in Orleans Parish after Hurricane Katrina.

Discussion

Motivated by the idea that post-disaster “impediments” (e.g., damage to housing and property) delay migration to and, thus, population recovery in disaster-affected areas (Green et al. 2007:311), we considered the potential role of stage migration as a source of population recovery in Orleans Parish after Hurricane Katrina. Given the migration motivations, decisions, and behaviors of actors, especially those displaced from their homes during natural disasters, there are strong reasons for migrating toward and eventually to disaster-affected areas through intermediary destinations (Chamlee-Wright and Storr 2009; Ehrenfrucht and Nelson 2012; Fussell 2009; Fussell and Harris 2014; Green et al. 2007; Sastry and Gregory 2014). Our study makes evident that understanding exactly how disaster-affected areas recover their populations through in-migration requires considering not only how places in a migration system are directly connected to one another by migration (Curtis et al. 2015; Fussell et al. 2014), but also how places are connected indirectly to one another via intermediary destinations. In this way, the entire migration system is potentially implicated in the population recovery of disaster-affected areas.

As we noted at several points along the way, the primary limitation of this paper concerns the data, which prevent direct assessments of stage migration as a source of population recovery in disaster-affected areas, including Orleans Parish. In an ideal world, the measurement of stage migration flows to disaster-affected areas starts with longitudinal data on actors’ migration patterns, information which is then “aggregated up” to study place-to-place migration patterns through intermediary destinations. In practice, however, the available data are limited to place- to-place migration flows in defined time intervals. Consequently, throughout this paper, we have been very careful to emphasize that our estimates of stage migration flows to Orleans Parish after Hurricane Katrina represent upper bounds, and thus *potential* stage migration.

This unavoidable data limitation is outweighed by two important contributions of our work. First, at a theoretical level, we connected research on migration systems theory (Curtis et al. 2015; Fussell et al. 2014; Mabogunje 1970; Bakewell 2013) with earlier work on stage

migration (Conway 1980; Hägerstrand 1957; Plane et al. 2005; Skeldon 1977). To our knowledge, these two theoretical bodies of research have not been linked explicitly, yet they have much in common and much to offer in terms of theorizing about processes of post-disaster population recovery through migration systems in which places are directly *and* indirectly connected to one another by migration. Importantly, our exploratory analysis of stage migration raises the prospect of continued migration, albeit through intermediary destinations, even when migration to disaster-affected areas is impeded and, thus, delayed.

The second contribution of this paper is substantive in nature. While the hazards (e.g., precipitation, wind, and temperature) associated with many natural disasters are often local phenomena, the ability of places adversely affected by them to recover is not. How places are connected to other places is ultimately another way of saying that places are interdependent. While we conceptualized and measured these interdependencies with respect to migration flows and population recovery, this is but one example. Other examples might include flows of capital, information, and goods and services. These interdependencies are spatially variable, with some places more strongly implicated than others (Curtis et al. 2015; Fussell et al. 2014). In a world that is changing with respect to the frequency, type, and severity of disasters, it is important to take these interdependencies into account, especially when preparing for, coping with, and responding to natural disasters.

In summary, our work reveals something hitherto unappreciated in studies of disaster and migration. While only asserted in other studies (e.g., Curtis and Schneider 2011), our work shows how population displacement from and, ultimately, recovery in a disaster-affected area ripples through migration systems, both directly and indirectly, redistributing populations as a means of coping with and recovering from a disaster's impacts. Such a perspective suggests a number of important and timely questions. First, while we focused on one place that recovered its population after a disaster, future research might also consider how places fail to recover their populations (McLeman 2011). Relatedly, what types of places do actors displaced by disasters migrate to, and, with respect to the work of this paper, by which pathways do actors reach these destinations? Finally, it goes without saying that hurricanes, let alone one hurricane such as Hurricane Katrina, do not exhaust the diversity of natural hazard events and their implications for human populations.

Accordingly, future research might also consider heterogeneity among natural hazard events (e.g., floods and sea level rise) (Curtis and Schneider 2011), as well as the pace of onset (e.g., rapid versus slow) and desistance (Laczko and Aghazarm 2009). As climate change produces more intense and frequent natural hazard events and populations are increasingly exposed to the risk of these events, understanding migration as an adaptive response becomes more urgent. Our work promotes greater understanding of multi-scale human climate adaptation via recovery migration.

References

- Bakewell O. Relaunching migration systems. *Migration Studies*. 2013
- Chamlee-Wright E, Storr VH. 'There's no place like New Orleans': Sense of place and community recovery in the Ninth Ward after Hurricane Katrina. *Journal of Urban Affairs*. 2009; 31(5):615–634.
- Colten C, Kates RW, Laska SB. Three years after Katrina: Lessons for community resilience. *Environment*. 2008; 50(5):36–47.

- Conway D. Step-wise migration: Toward clarification of the mechanism. *International Migration Review*. 1980; 14(1):3–14. [PubMed: 12337440]
- Curtis KJ, Fussell E, DeWaard J. Recovery migration after Hurricanes Katrina and Rita: Spatial concentration and intensification in the migration system. *Demography*. 2014; 52(4):1269–1293. [PubMed: 26084982]
- Curtis KJ, Schneider A. Understanding the demographic implications of climate change: Estimates of localized population predictions under future scenarios of sea-level rise. *Population & Environment*. 2011; 33(1):28–54.
- Ehrenfeucht R, Nelson M. Young professionals as ambivalent change agents in New Orleans after the 2005 hurricanes. *Urban Studies*. 2012; 50:825–841.
- Elliott JR. Natural hazards and residential mobility: General patterns and racially unequal outcomes in the United States. *Social Forces*. 2014
- Engels RA, Healy MK. Measuring interstate migration flows: An origin-destination network based on Internal Revenue Service records. *Environmental Planning A*. 1981; 13(11):1345–1360.
- Finch C, Emrich CT, Cutter SL. Disaster disparities and differential recovery in New Orleans. *Population and Environment*. 2010; 31:179–202.
- Fussell E. Hurricane chasers in New Orleans: Latino immigrants as a source of a rapid response labor force. *Hispanic Journal of Behavioral Sciences*. 2009; 31(3):375–394.
- Fussell E, Curtis KJ, DeWaard J. Recovery migration to the City of New Orleans after Hurricane Katrina: A migration systems approach. *Population and Environment*. 2014; 35(3):305–322. [PubMed: 24729651]
- Fussell E, Harris E. Homeownership and housing displacement after Hurricane Katrina among low-income African-American mothers in New Orleans. *Social Science Quarterly*. 2014; 95(4):1086–1100. [PubMed: 26392638]
- Fussell E. The long-term recovery of New Orleans' population after Hurricane Katrina. *American Behavioral Scientist*. 2015; 59(10):1231–1245. [PubMed: 26880853]
- Green R, Bates LK, Smyth A. Impediments to recovery in New Orleans' Upper and Lower Ninth Ward: One year after Hurricane Katrina. *Disasters*. 2007; 31(4):311–335. [PubMed: 18028156]
- Greenwood, MJ. Internal migration in developed countries. In: Rozenzweig, MR.; Stark, O., editors. *Handbook of Population and Family Economics*. Vol. 2. New York, NY: Elsevier; 1997. p. 647–720.
- Gross, E. Statistics of Income Division. Washington, DC: Internal Revenue Service; 2005. Internal Revenue Service area-to-area migration data: Strengths, limitations, and current trends.
- Hägerstrand, T. Migration and area: Survey of a sample of Swedish migration fields and hypothetical considerations on their genesis. In: Hannerberg, D.; Hägerstrand, T.; Odeving, B., editors. *Migration in Sweden: A Symposium*. Lund: Gleerup; 1957. p. 27–158.
- Isserman AM, Plane DA, McMillen DB. Internal migration in the United States: An evaluation of federal data. *Review of Public Data Use*. 1982; 10(4):285–311.
- Kamel N. Social marginalisation, federal assistance and repopulation patterns in the New Orleans Metropolitan Area following Hurricane Katrina. *Urban Studies*. 2012; 49(14):3211–3231.
- Kates RW, Coltan CE, Laska S, Leatherman SP. Reconstruction of New Orleans after Hurricane Katrina: A research perspective. *PNAS*. 2006; 103(40):14653–14660. [PubMed: 17003119]
- Laczko, F.; Aghazarm, C. *Migration, Environment, and Climate Change: Assessing the Evidence*. Geneva: International Organization for Migration (IOM); 2009.
- Mabogunje AL. A systems approach to a theory of rural-urban migration. *Geographic Analysis*. 1970; 2(1):1–18.
- McCarthy, K.; Peterson, DJ.; Sastry, N.; Pollard, M. *The Repopulation of New Orleans after Hurricane Katrina*. Santa Monica, CA: Rand Gulf States Policy Institute; 2006.
- McLeman, RA. *Climate and Human Migration: Past Experience, Future Challenges*. New York, N.Y.: Cambridge University Press; 2014.
- McLeman RA. Settlement abandonment in the context of global environmental change. *Global Environmental Change*. 2011; 21S:S108–S120.

- Molloy R, Smith CL, Wozniak A. Internal migration in the United States. *Journal of Economic Perspectives*. 2011; 25(3):173–196.
- Olshansky RB, Chang S. Planning for disaster recovery: Emerging resource needs and challenges. *Progress in Planning*. 2009; 72(4):200–209.
- Pierce, K. Statistics of Income Bulletin, Statistics of Income. Washington, D.C.: Internal Revenue Service; 2015. SOI migration data, A new approach: Methodological improvements for SOIC's United States population migration data, calendar years 2011–2012.
- Plane DA, Henrie CJ, Perry J. Migration up and down the urban hierarchy and across the life course. *PNAS*. 2005; 102(43):15313–15318. [PubMed: 16230633]
- Plane DA, Rogerson PA. Dynamic flow modeling with interregional dependency effects: An application to structural change in the U.S. migration system. *Demography*. 1986; 23(1):91–104. [PubMed: 3956810]
- Plyer, A.; Ortiz, E. Greater New Orleans Community Data Center. New Orleans Research Data Center; 2011. Who lives in New Orleans and the metro area now?. <http://www.datacenterresearch.org/>
- Sastry N, Gregory J. The location of displaced New Orleans residents in the year after Hurricane Katrina. *Demography*. 2014; 51(3):753–775. [PubMed: 24599750]
- Sjaastad LA. The costs and returns of human migration. *Journal of Political Economy*. 1962; 70(5):80–93.
- Skeldon R. The evolution of migration patterns during urbanization in Peru. *Geographical Review*. 1977; 67:394–411.
- U.S. Census Bureau. Population Division. Washington, D.C.: United States Census Bureau; 2014. Annual estimates of the resident population: April 1, 2010 to July 1, 2014.
- U.S. Census Bureau. Population Division. Washington, D.C.: United States Census Bureau; 2011. Table 1. Intercensal estimates of the resident population for counties of Louisiana: April 1, 2000 to July 1, 2010.
- Vachon, MC. Doctoral Dissertation. Syracuse University: Department of Economics; 2014. The impact of local labor market conditions on migration: Evidence from the Bakken oil boom.
- Vale, LJ.; Campanella, TJ. Introduction: The cities rise again. In: Vale, LJ.; Campanella, TJ., editors. *The Resilient City: How Modern Cities Recover from Disaster*. New York: Oxford University Press; 2005. p. 3-26.
- Wang F, Tang Q, Wang L. Post-Katrina population loss and uneven recovery in New Orleans, 2000–2010. *Geographical Review*. 2014; 104(3):310–327.
- Zlotnik, H. Empirical identification of international migration systems. In: Kritz, MM.; Lim, LL.; Zlotnik, H., editors. *International Migration Systems: A Global Approach*. Oxford: Clarendon Press; 1992. p. 19-40.

Figure 1.
Population Size and Annual Percent Change in Population: Orleans Parish, 2000–2014
Source: U.S. Census Bureau (2011, 2014)

Panel A: Longitudinal Mapping

Panel B: Synthetic Mapping

Figure 2.
Mapping of Data to Underlying Process of Stage Migration

M(1) =	<i>i</i>	<i>k</i>	<i>j</i>	Σ	P(1) =	<i>i</i>	<i>k</i>	<i>j</i>	Σ
	45	15	40	100		0.450	0.150	0.400	1.000
	15	45	40	100		0.150	0.450	0.400	1.000
	25	25	50	100		0.250	0.250	0.500	1.000

M(2) =	<i>i</i>	<i>k</i>	<i>j</i>	Σ	P(2) =	<i>i</i>	<i>k</i>	<i>j</i>	Σ
	30	25	30	85		0.353	0.294	0.353	1.000
	25	30	30	85		0.294	0.353	0.353	1.000
	20	20	90	130		0.154	0.154	0.692	1.000

M(3) =	<i>i</i>	<i>k</i>	<i>j</i>	Σ	P(3) =	<i>i</i>	<i>k</i>	<i>j</i>	Σ
	20	35	20	75		0.267	0.467	0.267	1.000
	35	20	20	75		0.467	0.267	0.267	1.000
	15	15	120	150		0.100	0.100	0.800	1.000

Figure 3.

Hypothetical System of Migration Flows among Three Counties in Three Time Intervals

$$\mathbf{P}(\mathbf{1-2}) = \begin{matrix} & \begin{matrix} i & k & j \end{matrix} \\ \begin{matrix} i \\ k \\ j \end{matrix} & \begin{bmatrix} 0.264 & 0.247 & 0.489 \\ 0.247 & 0.264 & 0.489 \\ 0.239 & 0.239 & 0.523 \end{bmatrix} \end{matrix}$$

$$\mathbf{P}(\mathbf{1-3}) = \begin{matrix} & \begin{matrix} i & k & j \end{matrix} \\ \begin{matrix} i \\ k \\ j \end{matrix} & \begin{bmatrix} 0.235 & 0.238 & 0.527 \\ 0.238 & 0.235 & 0.527 \\ 0.227 & 0.227 & 0.545 \end{bmatrix} \end{matrix}$$

$$\mathbf{M}(\mathbf{1-2}) = \begin{matrix} & \begin{matrix} i & k & j \end{matrix} \\ \begin{matrix} i \\ k \\ j \end{matrix} & \begin{bmatrix} 26 & 25 & 49 \\ 25 & 26 & 49 \\ 24 & 24 & 52 \end{bmatrix} \end{matrix}$$

$$\mathbf{M}(\mathbf{1-3}) = \begin{matrix} & \begin{matrix} i & k & j \end{matrix} \\ \begin{matrix} i \\ k \\ j \end{matrix} & \begin{bmatrix} 23 & 24 & 53 \\ 24 & 23 & 53 \\ 23 & 23 & 55 \end{bmatrix} \end{matrix}$$

$$\mathbf{P}^s(\mathbf{1-2}) = \begin{matrix} & \begin{matrix} i & k & j \end{matrix} \\ \begin{matrix} i \\ k \\ j \end{matrix} & \begin{bmatrix} & 0.062 & 0.053 \\ 0.062 & & 0.053 \\ 0.074 & 0.074 & \end{bmatrix} \end{matrix}$$

$$\mathbf{P}^s(\mathbf{1-3}) = \begin{matrix} & \begin{matrix} i & k & j \end{matrix} \\ \begin{matrix} i \\ k \\ j \end{matrix} & \begin{bmatrix} & 0.094 & 0.120 \\ 0.094 & & 0.120 \\ 0.140 & 0.140 & \end{bmatrix} \end{matrix}$$

$$\mathbf{M}^s(\mathbf{1-2}) = \begin{matrix} & \begin{matrix} i & k & j \end{matrix} \\ \begin{matrix} i \\ k \\ j \end{matrix} & \begin{bmatrix} & 6 & 5 \\ 6 & & 5 \\ 7 & 7 & \end{bmatrix} \end{matrix}$$

$$\mathbf{M}^s(\mathbf{1-3}) = \begin{matrix} & \begin{matrix} i & k & j \end{matrix} \\ \begin{matrix} i \\ k \\ j \end{matrix} & \begin{bmatrix} & 9 & 12 \\ 9 & & 12 \\ 14 & 14 & \end{bmatrix} \end{matrix}$$

Figure 4.

Hypothetical System of Migration Flows among Three Counties in Three Time Intervals:
Cumulative and Stage Migration

Figure 5.

Total Annual, Cumulative, and Stage Migration Flows to Orleans Parish: Post-Katrina

Figure 6.

Difference in Total Annual, Cumulative, and Stage Migration Flows to Orleans Parish: Pre-Versus Post-Katrina

Table 1

Joint Probability Matrices of County-to-County Migration: Pre- and Post-Katrina

	Pre-Katrina	Post-Katrina
1 Year	P(2004)	P(2006)
2 Years	P(2004)²	P(2006–07)
3 Years	P(2004)³	P(2006–08)
4 Years	P(2004)⁴	P(2006–09)
5 Years	P(2004)⁵	P(2006–10)