Assessment on hurricane induced population migration in the CONUS – a case study of Hurricane Sandy

Jinwen Xu, Ran Tao, Yi Qiang

ABSTRACT: In the wake of climate change, understanding human migration patterns in response to weather-related disasters is important. This study harnesses PUMS data to identify migration trends following Hurricane Sandy, aiming to explain the interaction between disaster-induced relocations and socioeconomic variables. This study utilized a data-fusion methodology to clean and process disaster data from multiple sources. Multinomial logistic regression models were used to identify significant variables of disaster-induced population migration. The findings indicate that migration patterns depicted in PUMS data can reflect the disruption caused by Hurricane Sandy. Certain socioeconomic demographics, notably those with advanced education, unmarried individuals, and non-US citizens, exhibited a higher propensity to relocate in response to the hurricane. Conversely, older adults and the non-black population were more inclined to remain within the region. A variance in relocation preferences was observed across different societal groups, suggesting that those with higher educational credentials were more prone to move away from impacted areas, whereas less educated individuals often stayed within. These insights are pivotal, offering strategic input for local community adaptation and planning in post-disaster scenarios. The analytical framework applied in this study, focused on Hurricane Sandy, presents a model that can be extended to evaluate relocation impacts stemming from similar catastrophic events.

KEYWORDS: migration, hurricane, mobility, socio-economic status, resilience

Introduction

Hurricane induced economic loss has cost American over $100 billion in recent years (Khajwal & Noshadravan, 2020). In response to the devastation of hurricanes and subsequent disasters such as flooding, relocation has been used as a common strategy for individuals seeking to mitigate the impact on their lives, particularly when their homes suffer severe damage (Perry & Lindell, 1997). While numerous studies have focused on disaster-related mobility and migration, they often remain specific to a specific spatial scale or an individual case, limiting the transferability of their findings across different scenarios (Regmi et al., 2020; Sastry & Gregory, 2014). With the accumulation of data in the Public Use Microdata Sample (PUMS) by U.S. Census Bureau, the dataset now allows for more comprehensive analysis of migration patterns following such disasters. In accordance with disaster information collected from Emergency Management Agency (FEMA), the relocation decision made by people living in impacted areas can be assessed through multiple aspects. This study leverages time-series PUMS data from 2007 to 2013 and make Hurricane Sandy as an example to explore the detailed insights into the spatial and temporal patterns of population movement before, during, and after the hurricane within the Contiguous United States. This study aims to answer the following research questions: 1) Can PUMS data reflect changes in post-disasters population movement? 2) What socio-

economic conditions may be related to relocation decisions made by people living in the disaster-impacted area? 3) Is the socio-economic status of people living in the impacted area related to their destination choices?

Method

Data acquisition and processing

First, the FEMA major disaster declarations focus on the areas affected by disasters. Hurricane Sandy-related declarations were selected by the declaration title "Hurricane Sandy" in the dataset using Python. Second, boundary data was collected from two sets of PUMAs released by the U.S. Census: the 2000 and the 2010 versions. The choice of PUMA version is determined by the migration data collection period: pre-2012 data corresponds with 2000 PUMA, and 2012 or later with 2010 PUMA. A crosswalk resource facilitated the translation of all PUMA data to the 2010 standard. Third, individual-level data from the 1-year Public Use Microdata Sample (PUMS) by the U.S. Census Bureau was analyzed. This dataset includes details on individual's socioeconomic status and relocation choices. Migration data within PUMS uses MIGPUMA, a spatial unit that may aggregate several PUMAs for privacy protection. Consequently, migration analysis adheres to the 2010 MIGPUMA for consistency across the study.

Then, we identified the impacted areas by overlaying PUMA boundaries with county boundaries that have major disaster declaration orders in Python. Then, we selected the PUMS records in the impacted area and dissolved the polygons in the same MIGPUMA. Relocation distances before and after Hurricane Sandy were aggregated, contrasting the movements from areas affected by Hurricane Sandy with those from unaffected regions (rest of the CONUS). The relocation destinations and the number of individuals who chose to migrate in 2012 (when Hurricane Sandy occurred) were plotted using the choropleth map.

Logistic regression

Two multinomial logistic regression models were used to assess the relocation decision and relocation destination in the impacted areas by Hurricane Sandy. The first multinomial regression model was used to answer what make an individual move or not by assessing the relationship between the socio-economic status of population living in impacted areas and their relocation decisions, while the second model was utilized to find connections between their socio-economic status and relocation destination choices in the US. According to Sastry et al. (2014), socio-economic variables used in this study include race (2 levels), education attainment (5 levels), age (3 levels), sex (2 levels), marital status (2 levels), and citizenship (2 levels) (see Table 1).

$$P_D = \begin{cases} 1 \ if \ individual \ relocated \\ 0 \ if \ individual \ not \ relocated \end{cases}$$

$$logit[P_D(ref.=1)]$$
$$= \beta_{race}x_{race} + \beta_{education}x_{education} + \beta_{age}x_{age}$$
$$+ \beta_{sex}x_{sex}\beta +_{marriage} x_{marriage} + \beta_{citizen}x_{citizen}$$

where P_D is the probability of a resident in the impacted area choosing to relocate to a certain destination, and β_n is the coefficient associated with each independent variable input x_n. The independent variables are the socio-economic status of each individual, including race, education, age, gender, marital status, and citizenship.

Similarly, the destination choices in 2012 were analyzed using multinomial logistic regression model across three relocation spatial resolutions: 1) within the same PUMA vs. outside the PUMA, 2) within the same state vs. outside the state, 3) within the same region vs. outside the region.
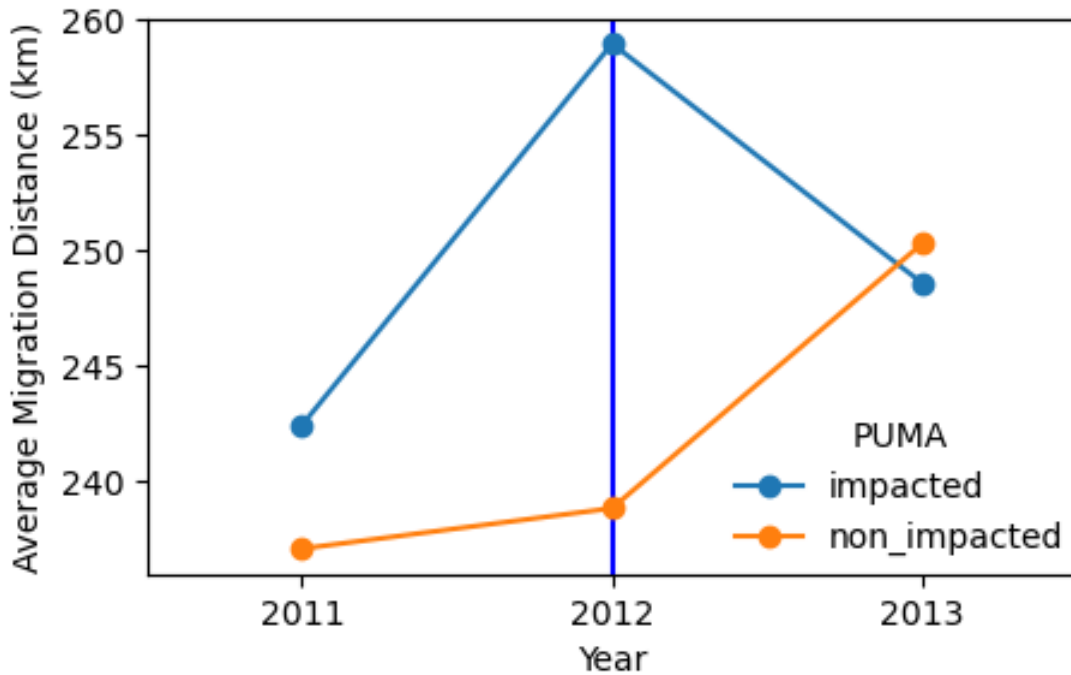
Results

Figure 1. Average distance of migrants who reside in the impacted area vs. non-impacted area by Hurricane Sandy in 2012, with centroid locations for each MIGPUMA being used for origin and destination while distance calculation is based on the USA Contiguous Albers Equal Area Conic projection.

Figure 1 illustrates the result of average distance calculation within the CONUS before, during, and after Hurricane Sandy. A notable increase in the average migration distance for areas affected by Hurricane Sandy was observed in 2012, suggesting a significant relocation response to the disaster. The distribution of relocation destinations of people who live in the impacted area highlights Boston and its suburbs, as well as Manhattan and Brooklyn in New York City, as the primary destinations for their displacements in 2012 (Figure 2). Additional relocation hotspots include Cleveland in Ohio, Los Angeles in

California, and Miami in Florida, reflecting a diverse set of urban centers that absorbed populations moving away from the hurricane's impact zone.
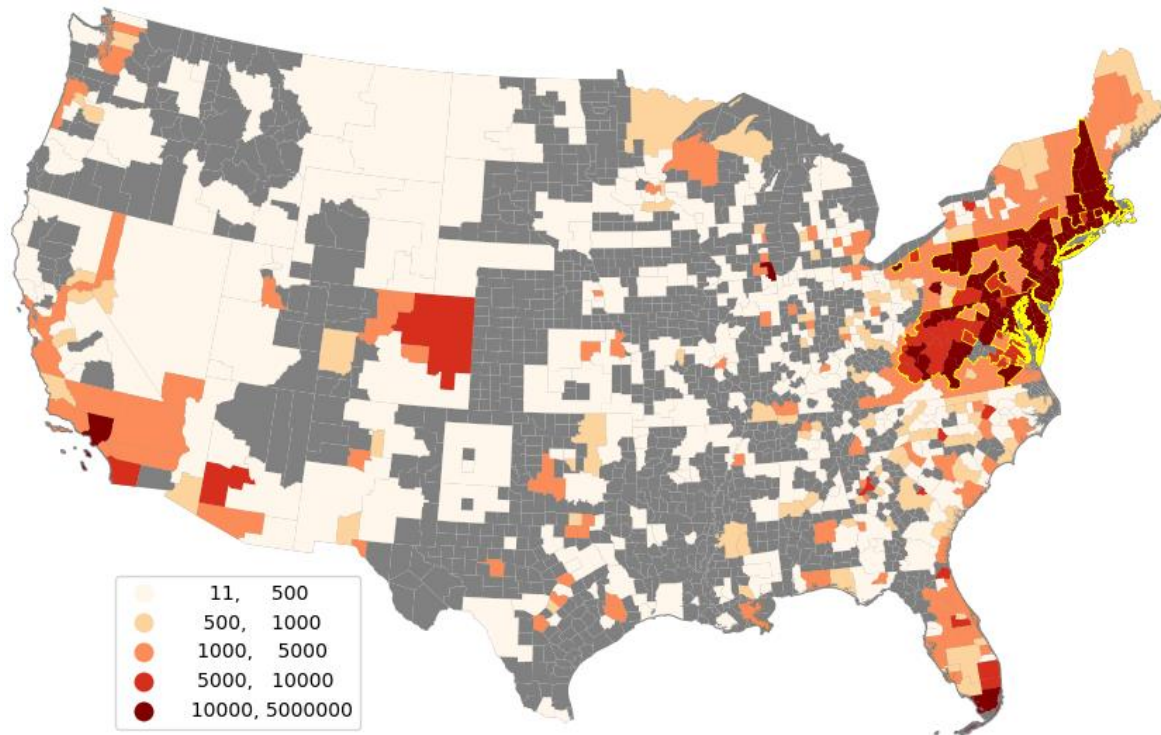

Figure 2. Spatial distribution of relocation population from impacted area by Hurricane Sandy (highlighted with a yellow outline) in 2012 within the CONUS.

Table 1 shows the result of a multinomial logistic regression model on socio-economic factors influencing relocation decisions among residents in areas impacted by Hurricane Sandy, compared across three different years: pre-disaster (2011), in-disaster (2012), and post-disaster (2013). Compared to black, nonblack is associated with a lower likelihood of moving in all three years, with the strongest effect seen in 2012 during the disaster. Higher educational attainment, compared to having only a high school diploma, generally increases the likelihood of relocation, particularly for those with a bachelor's or graduate degree. Meanwhile, people without a high school diploma also shows higher likelihood of relocation. Younger individuals (25–39) are more likely to move compared to the 40–59 age group, and this tendency is particularly strong after the disaster. In contrast, individuals aged 60 and over are less likely to move. Non-U.S. citizens are more likely to relocate than U.S. citizens, with the effect being most pronounced during the disaster year. Individuals who never married are more likely to move compared to those who have ever been married. Males are slightly more likely to relocate than females, though the effect is small.

Table 1: Multinomial logistic regression models of relocation decision among residents living in Sandy-impacted areas by year.

Variable	Pre-disaster (2011) Movers vs. Non-movers		In-disaster (2012) Movers vs. Non-movers		Post-disaster (2013) Movers vs. Non-movers	
Race (ref. = black)						
Nonblack	-0.178 ***	(0.002)	-0.205 ***	(0.002)	-0.128 ***	(0.002)

Education (ref. = high school)						
High school dropout	0.199 ***	(0.002)	0.175 ***	(0.002)	0.227 ***	(0.002)
Some college	0.038 ***	(0.002)	0.002	(0.002)	0.035 ***	(0.002)
Bachelor's degree	0.095 ***	(0.002)	0.064 ***	(0.002)	0.104 ***	(0.002)
Graduate degree	0.165 ***	(0.002)	0.122 ***	(0.002)	0.214 ***	(0.002)
Age (ref. = 40–59)						
25–39	0.865 ***	(0.001)	0.858 ***	(0.001)	0.886 ***	(0.001)
60+	-0.427 ***	(0.002)	-0.396 ***	(0.002)	-0.333 ***	(0.002)
Sex (ref. = female)						
Male	0.061 ***	(0.001)	0.050 ***	(0.001)	0.070 ***	(0.001)
Marital status (ref. = ever married)						
Never married	0.259 ***	(0.001)	0.264 ***	(0.001)	0.208 ***	(0.001)
Citizenship (ref. = U.S.)						
Non-U.S.	0.445 ***	(0.002)	0.457 ***	(0.002)	0.366 ***	(0.002)

Notes: Standard errors are in parentheses; Number of records in 2011 = 311,370, Number of records in 2012 = 347,739, Number of records in 2013 = 350,106. Effects are estimated using restricted data from PUMS data before, during and after Hurricane Sandy with weights
†p < .10; *p < .05; **p < .01; ***p < .001

In Table 2, we assessed the relocation choices by residents in areas impacted by Hurricane Sandy in 2012. The larger positive number means that this type of population is more likely to relocate within the spatial unit level when compared to reference level and vice versa. We found that nonblack individuals are less likely to relocate outside the same PUMA within the state and to move outside the state or region compared to black individuals. People with higher educational levels than high school (some college, bachelor's degree, graduate degree) were more likely to move outside their PUMA, state, or region. The magnitude of this tendency increases with the education level attained. Compared to the 40–59 reference group, younger individuals (25–39) were more likely to relocate outside their PUMA but within the state. However, their propensity to move outside the region was not significantly different. The 60+ age group did not have a significant difference in the likelihood of relocating outside the same PUMA and the result even indicates that they were more likely to move outside the state and region, which is possibly due to the exclusion of individuals who decided not to relocate. Males were more likely to relocate outside their PUMA within the state and showed a slight propensity to move outside the region compared to females. Never-married individuals were more likely to relocat outside the PUMA within the state compared to those ever married, but they were less likely to relocate outside the region. Non-U.S. citizens are less likely to move within the same region than within the same PUMA, but are significantly more likely to move outside the region compared to U.S. citizens.

Table 2: Multinomial logistic regression models of relocation destination among residents living in Sandy-impacted areas (who migrated) in 2012.

Variable	Relocate outside the PUMA but within the state vs. within the same PUMA		Relocate outside the state but within the region vs. within the same PUMA		Relocate outside the region vs. within the same PUMA	
Race (ref. = black)						
Nonblack	-0.072 ***	(0.004)	-0.031 ***	(0.006)	-0.216 ***	(0.004)
Education (ref. = high school)						
High school dropout	0.102 ***	(0.005)	-0.408 ***	(0.005)	-0.034***	(0.006)
Some college	0.209 ***	(0.004)	0.376 ***	(0.004)	0.420 ***	(0.005)
Bachelor's degree	0.433 ***	(0.004)	0.637 ***	(0.004)	0.953 ***	(0.005)
Graduate degree	0.419 ***	(0.005)	0.780 ***	(0.004)	1.261 ***	(0.005)

Age (ref. = 40–59)						
25–39	0.201 ***	(0.003)	0.176 ***	(0.003)	0.055 ***	(0.004)
60+	-0.001	(0.005)	0.045 ***	(0.004)	0.219 ***	(0.005)
Sex (ref. = female)						
Male	0.162 ***	(0.003)	0.219 ***	(0.003)	0.012 ***	(0.003)
Marital status (ref. = ever married)						
Never married	0.095 ***	(0.003)	0.002	(0.005)	-0.082 ***	(0.004)
Citizenship (ref. = U.S.)						
Non-U.S.	-0.288 ***	(0.004)	-0.193 ***	(0.003)	0.926 ***	(0.004)

Notes: Standard errors are in parentheses; Number of records = 31,244. Effects are estimated using restricted data from PUMS data before, during and after Hurricane Sandy with weights. Regions are defined by U.S. Census Bureau.

†$p < .10$; *$p < .05$; **$p < .01$; ***$p < .001$

Conclusions

This study used PUMS data to analyze the population migration patterns resulting from Hurricane Sandy's impact. The study provides a methodology for preparing and analyzing census sample data to evaluate both migration trends and socio-economic characteristics. The result indicates that PUMS data can accurately capture the displacement caused by the hurricane and highlights certain socio-economic attributes, such as higher educational attainment, marital status, and citizenship, that influence relocation tendency during such events. Conversely, older and nonblack populations demonstrated a tendency to stay within the region. the study observed that educational level influenced destination preference, with more educated individuals moving beyond regional boundaries, whereas those lacking a high school diploma often stayed within the state, which could potentially raise climate justice issue. These insights have practical implications, offering guidance for building resilience and development to better accommodate migration flows and address future disaster-related challenges. While this study specifically focuses on Hurricane Sandy, the developed framework is transferable and can be applied to broader contexts to understand the effects of hurricanes on population movements. In the next step, we are extending this methodology to all major hurricane events happened in the US in the past 15 years.

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Jinwen Xu, Research Associate, GIS Center, Florida International University, Miami, FL 33199

Yi Qiang, Associate Professor, School of Geosciences, University of South Florida, Tampa, FL 33620

Ran Tao, Assistant Professor, School of Geosciences, University of South Florida, Tampa, FL 33620