The Role of Gentrification in Predicting BMI and Self-Rated Health Among Survivors of Hurricane Katrina

Introduction

Socioeconomic and racial disparities in health in the US are geographically patterned (Diez Roux, 2001; S. Macintyre, Ellaway, & Cummins, 2002). Exposure to neighborhood disadvantage, particularly concentrated poverty and segregation, contribute to a broad range of negative health outcomes, including elevated BMI (Corral et al., 2015), self-rated health (Gibbons & Yang, 2014 2233) blood pressure (Chaix, Merlo, Evans, Leal, & Havard, 2009), heart disease (Jones, 2013), preterm birth (Britton & Shin, 2013), and premature mortality (S. V. Subramanian, Chen, Rehkopf, Waterman, & Krieger, 2005). As a result, many poverty scholars have argued for the deconcentration of poverty (Wilson, 1987), by mixing households of different SES, which many expect to reduce or ameliorate these risks.

Though research has established robust associations between area economic deprivation and unhealthy residents (Robert, 1999; S. V. Subramanian et al., 2005), there is limited research about how changes in the demographic, social and cultural context of a neighborhood affect health outcomes [1]. Previous literature has explored contemporaneous and lagged health effects of neighborhoods (Ellen, Mijanovich, & Dillman, 2001), how individual's changing neighborhoods affects their health (Ludwig et al., 2011), how individual economic position affects neighborhood of residence, and how health can impact neighborhood selection (M. C. Arcaya, Subramanian, Rhodes, & Waters, 2014; James et al., 2015). However, there is limited knowledge of how socioeconomic and cultural changes *within* a neighborhood causally affect

residents' health. This is in part because it is difficult to show that neighborhood changes *cause* changes in health, as low-income populations are likely to have poorer health to begin with, and to live in more resource deprived neighborhoods than more affluent populations [2].

Gentrification – a process of demographic, social, cultural and political change resulting from an influx of new amenities, higher (SES) residents, investment and increased housing prices – is one form of neighborhood change, and has increased in scope and scale across many U.S. metropolitan areas in the past two decades [3]. However, there is limited evidence to demonstrate the implications of gentrification for health [4], and the available literature is mostly from observational studies lacking the methodological rigor to draw causal inferences [1]. In this article, we improve upon previous work on gentrification and neighborhood change and health by conducting a quasi-experimental multivariate hierarchical analysis to test various associations between neighborhood gentrification, and self-rated health and BMI.

This study uses data from the Resilience in Survivors of Katrina (RISK) project, geocoded to census tracts, and merged with a census-derived measure of neighborhood gentrification. The RISK project is a longitudinal study of low-income parents, predominantly non-Hispanic Black single mothers, who participated in a New Orleans-based study before and after Hurricane Katrina. Our study uses three waves of the RISK dataset, from 2003-2004 before Katrina, and 2006-2007 and 2008-2009, after Katrina (2005) to track participants across neighborhoods. Katrina displaced all participants, at least temporarily, from New Orleans, though about half returned to their pre-Katrina parish. Residents had little or no control over neighborhood placement immediately following the storm. This near-random displacement after Katrina created a natural experiment, which we exploit in our study design.

Though gentrification began in New Orleans well before the storm, the rebuilding of the city exacerbated existing trends in gentrification and spatial inequity [5, 6]. To identify how health outcomes would have evolved in the absence of gentrification, we examine BMI and self-rated health by comparing outcomes among those placed into neighborhoods that underwent gentrification between 2000 and 2005-2009, to those placed in low-income communities that did not experience gentrification, both before and after Katrina.

We employed a difference-in-differences approach similar to that used in a recent quasi-experimental study by Deryugina & Moliter 2018, which found that eight years after Katrina, elderly and disabled Katrina victims that moved to low-mortality regions had significantly lower mortality rates than those who moved to high-mortality regions [7]; however, that study was potentially subject to bias from voluntary neighborhood selection. Our research aims to contribute to the urban health literature by assessing the causal effect of place on health, using a quasi-experimental design, examining health outcomes other than mortality, and focusing on a low-income population who are the most exposed and vulnerable to effects of gentrification.

We examine changes in neighborhood gentrification and change in our measures of health, between the three waves of the study. We hypothesize that being assigned to a neighborhood with a higher level of gentrification will predict worse health outcomes; the risks of further displacement, higher housing costs, neighborhood destabilization and breakdown of social networks will outweigh the potential benefits of increased investment and influx of higher SES residents. There is also limited scholarship on gentrification that considers the role of racial stratification in shaping the trajectory and implications of gentrifying neighborhoods [8, 9]. We address this gap by including tests of effect modification by individual race and neighborhood majority racial composition.

Methods

STUDY DESIGN

We took advantage of the near random assignment to neighborhoods post-Katrina, and employ a quasi-experimental Intent-To-Treat (ITT) approach, that looked at neighborhood of assignment post-Katrina (2006). Using an ITT approach, participants were analyzed based on their 2006 neighborhood assignment, regardless of whether they voluntarily stayed long-term or moved after assignment. We included data from the second follow-up wave, but participants' exposure remained in the first wave assigned neighborhoods. This study design avoids selection into neighborhoods in a non-random way, which would bias our estimate of the relationship between gentrification and health, and controls for unmeasured time-in varying confounders. Our primary analysis employed a difference-in-difference (DD) method to compare self-rated health among those assigned to a gentrified neighborhood versus assigned to an impoverished neighborhood (first difference) before and after Katrina (second difference).

DATA SOURCE

Data comes from the RISK project, a longitudinal study of 1,019 young, low-income predominantly African-American parents who survived Hurricane Katrina and lived in New Orleans or a surrounding parish in 2003. Data were collected initially in 2003-2004 (baseline) on participants living in New Orleans or a surrounding parish, as part of the Opening Doors Evaluation, a program designed to increase academic persistence in community colleges. All participants were between 18 and 34 years old, the parent of at least one dependent child had an income below 200% FPL, and had a high school diploma or equivalent. After Hurricane Katrina hit in August of 2005 during follow-up data collection, the study was redesigned to be the RISK project. Two follow-up waves have been conducted since then, one in 2006-2007 that surveyed

711 of the original respondents, and again in 2009-2010 with 752 respondents. We refer to the 2003-2004 data as "baseline," the 2006-2007 as "first follow-up wave," and 2009-2010 as "second follow-up wave." All data are self-reported, and the study was approved by the Princeton and Harvard Institutional Review Boards.

MEASURES

One geographic level, neighborhood, is considered in our multilevel analysis because it represents an administrative, economic and social membership that likely influences BMI at the individual level (level-1). Clustering due to shared context at the neighborhood level creates statistical dependence that, if not appropriately accounted for in analysis, can result in incorrect statistical estimates. We operationalize census tracts as neighborhoods because participants were geocoded to this census geography, they are relatively small geographic units (approximately 4,000 people), and data are available at the tract level over our study period. Though imperfect representations of neighborhoods, census tracts are the most commonly used administrative unit in multilevel neighborhood health studies (M. C. Arcaya et al., 2016), and there is evidence suggesting these geographies perform well for health research (Krieger et al., 2003). Further, many other studies of gentrification have used census tracts (Ellen & O'Regan, 2008; Hwang & Sampson, 2014; McKinnish, Walsh, & White, 2010).

EXPOSURE

Our primary exposure is an indicator of gentrification, based on the change in the ratio of the median household income in the census tract to the county median, among previously low-income census tracts (Ellen & O'Regan, 2011). Following a number of other studies, we utilized this relative measure of income to account for differences in wage levels across MSAs and years

[10]. Though researchers have operationalized gentrification in various manners-- including increases in household income, housing cost, percentage white, and education in formerly low-income neighborhoods- we followed several other studies in the literature and choose a metric based solely on income growth (Ellen & O'Regan, 2008; McKinnish et al., 2010, Landis 2016), because it uses administrative data that is available across the U.S., at the census tract level. Other studies found that this index correlated well with other metrics including, educational up-skilling, racial turnover, and housing rents (Sanghoon Lee & Lin, 2013), and produces similar results to more complex indices (Bostic & Martin, 2003; Ding et al., 2015).

For pre-Katrina (baseline), we measured the "gentrification index" as the change in census tract to county household median income from decennial Census 1990 to 2000. For the 2006-2007 wave we measure the difference in index between 2000 and 2005-2009 American Community Survey (ACS) 5-year estimates. We also consider whether the neighborhood was low-income, and therefore eligible for reinvestment, in the base year of the gentrification index: 1990 for the Pre-Katrina wave, and 2000 for post-Katrina. We define previously low-income census tracts as those with household median incomes in the bottom 40% of county median incomes. All participants were geocoded to census 2000 tracts boundaries, and 1990 census tract boundaries were normalized to 2000 census tract boundaries using the Longitudinal Tract Base (Logan, Xu, & Stults, 2014).

Following a number of other studies, [11-14], we categorized our gentrification index, and used a threshold of greater than 5 percentage point change in the census tract gentrification index to indicate substantial socioeconomic change (Ellen & O'Regan, 2011). Our categorical variable incorporates our measure of whether a neighborhood was eligible for reinvestment, helping to distinguish gentrifying neighborhoods from moderate or high income neighborhoods

that experience further economic ascension. Additionally, a continuous measure is more likely to – neighborhoods that are declining from – so categorizing the gentrification index allows us to measure the effects of gentrification in comparison to continuously low-income or declining neighborhoods. Likely to net-out any health effect as the continuous measure assumes a linear relationship between economically declining neighborhoods and increasing, which does not follow our hypothesis that both declining and gentrifying neighborhoods may detrimentally impact health. .

The categorical variable, our *Treatment* variable, indicates whether, between 2000 and 2005-2009 the post-Katrina assigned neighborhood gentrified, remained impoverished, appreciated, or depreciated. We defined these four mutually exclusive categories as follows: "Gentrifying" was defined as neighborhoods that were low-income in 2000, where the ratio of neighborhood to county household median income increased by 5 or more percentage points between 2000 and 2005-2009. "Impoverished" was low-income in 2000, and the ratio of household to county income either decreased or increased by less than five percentage points. "Depreciated" was affluent in 2000, and the ratio decreased or increased by less than five percentage points. "Appreciated" was affluent in 2000, and the ratio increased by 5 or more percentage points. We refer to this variable as “neighborhood categories.” Our categorical variable incorporates our measure of whether a neighborhood was eligible for reinvestment, helping to distinguish gentrifying neighborhoods from moderate or high income neighborhoods that experience further economic ascension. Additionally, a continuous measure assumes a linear relationship between the change in neighborhood economic status and resident health, while our categorical variable allows us to compare gentrifying neighborhoods to continuously low-income neighborhoods, our primary comparison of interest.

We also tested a three-level categorical variable that combined the appreciated and depreciated ("affluent" in 2000) categories. In all models, the impoverished category was the reference group. To test for sensitivity to the cut off threshold we replicate our analysis including gentrification as a binary indicator based on greater than or less than 5% change among previously low income neighborhoods, a continuous measure of the census tract to county median household income, a ten percentage point increase, and any positive change in the gentrification index.

COVARIATES

We considered the racialized implications of gentrification using three variables, as evidence suggests the powerful impact of race in neighborhood selection and how race/ethnicity shapes patterns of segregation and risk of neighborhood disinvestment and investment [15]. Previous research has found neighborhood racial segregation predicts higher risk of neighborhood gentrification (Hwang & Sampson, 2014) and is associated with both BMI (Corral et al., 2015 2230) and self-rated health (Gibbons & Yang, 2014), among Blacks. We use racial composition to assess the potential differential effects of gentrification by racial segregation. We calculated our measure as the 2000 racial/ethnic composition for the follow-up neighborhoods, and categorized neighborhoods where greater than 50% of the population was part of a particular racial group as majority White, majority Black or any other racial composition, which includes majority Hispanic and neighborhoods with no majority racial/ethnic composition [16] (Hwang & Sampson, 2014). We assess differences in neighborhood racial composition in 2000, the beginning of the gentrification window, for neighborhoods assigned post-Katrina. Our quasi-experimental design reduces the risk of neighborhood selection by race, so we do not adjust for potential confounding by residential segregation before Katrina. Instead, we run our adjusted

models separately for each of our neighborhood composition categories to test for differential impacts of gentrification based on the racial composition in the neighborhood and to help identify the possible unequal consequences of reinvestment based on the racial composition of communities [16].

We also included individual race/ethnicity (white, black, other) as a covariate to adjust for baseline imbalance between the control and treatment groups. We then tested for effect modification by individual race by running adjusted models separately for each of our racial categories to examine the potential differential effects of gentrification on participants of different races.

INDIVIDUAL COVARIATES

In addition to individual race/ethnicity, we adjusted for several characteristics to account for any baseline imbalance between the various treatment groups post-Katrina. These variables include race, welfare, and social support, measured at baseline. There was no evidence of an imbalance in age at baseline, but including this variable controls for time-specific effects. We tested for imbalance along additional demographic characteristics of the full sample, between the treatment and control groups (N=1,019) but found no evidence of imbalance for these characteristics (see Table 7). Age was measured as continuous; race was measured as categorical (Non-Hispanic White, Non-Hispanic Black, Other race/ethnicity, which included Asian and Hispanic); and social support was measured as continuous using a validated four-point scale of social support (Cutrona & Russell, 1987).

MODEL BUILDING

Statistical analysis

We used a multilevel data structure to make inference about the effects of an area-level exposure (gentrification) on individual level outcomes (BMI and self-reported health). We tested the appropriateness of a multilevel structure using likelihood ratio tests comparing the single, double, and triple level models and found that the more complex (three level) model was a better fit to the data. We, therefore, show the three-level models below. In all models, we clustered participants in baseline counties, as members reported in qualitative data collection that neighbors were likely to take the same bus out of New-Orleans and find homes in the same PK1 area.

Using LR tests for nested models, and AIC/BIC for non-nested models, we tested the appropriateness of multilevel (one versus two, and two versus three level) data structure. We found that the more complex model three-level model, with waves (i) nested in individuals (j) nested within neighborhoods (k) was appropriate for the data structure.

Our analysis used three waves of data for our quasi-experimental design, clustering observations within participants, and participants within neighborhoods. We clustered participants in baseline census tracts, as neighbors were more likely to board the same bus leaving New Orleans and resettle in the same area, return to the same New Orleans neighborhoods after Katrina, and to share sociodemographic profiles.

Our baseline model was a three-level model, with waves (i) nested within individuals (j) nested within neighborhoods (k). For interpretation, β_0 represents the average self-reported health Pre-Katrina (2003), for participants living in an impoverished neighborhood in 2006. Bracketed terms represent random effects associated with neighborhood, individual participant, and waves. The term v_{0k} is the neighborhood-specific residual that gives each neighborhood its own average self-reported health, u_{0jk} is the individual-specific residual, and $e_{0ij}$is the wave-

specific residual. Assuming residuals with a normal distribution and mean of zero, the model estimates σ_{v0}^2 as the between neighborhood variation in self-reported health, σ_{u0}^2 as the between individual, within neighborhood variation in self-reported health, and σ_{e0}^2 as the within neighborhood, within individual, between wave variation in self-reported health. We model the covariance as identity because we employ a single-level random effect.

We included a dummy variable for *Post*, where 1 indicated data from the 2006 and 2009 post-Katrina waves, and 0 indicated data from the pre-Katrina (2003) wave. We additionally tested creating an additional level for the 2009 wave. The *treatment* variable, the four-level categorical variable that indicated whether, between 2003 and 2006 the post-Katrina assignment neighborhood gentrified, stayed impoverished, appreciated, or depreciated, was included as three dummy variables with impoverished neighborhoods as the reference group.

Our main variable of interest was β_5, or the interaction term between the β_1(Post) and β_2(Gentrified). It can be interpreted as the average differential effect of being assigned to a gentrified neighborhood compared with the reference group (assigned to an impoverished neighborhood) post-Katrina. Our baseline model for the effect of gentrification on self-rated health is specified as follows.

$$
\begin{aligned}
&SelfRated\ Hlth_{2ijk} \\
&\quad = \beta_0 + \beta_1 Post_{ij} + \beta_2 Gentrified_k + \beta_3 Depreciated_k \\
&\quad + \beta_4 Appreciated_k + \beta_5 Post_{ij} * Gentrified_k \\
&\quad + \beta_6 Post_{ij} * Depreciated_k + \beta_7 Post_{ij} * Appreciated_k + (e_{0ijk} \\
&\quad + u_{0jk} + v_{0k}) \\
&\\
&\quad e_{0ij} \sim N(0, \sigma_{e0}^2) \\
&\quad u_{0j} \sim N(0, \sigma_{u0}^2) \\
&\quad k_{0j} \sim N(0, \sigma_{k0}^2)
\end{aligned}
$$

Sensitivity Analysis

To look for evidence of selective attrition, we compared mean demographics at baseline, among the full sample, sample of participants in the survey at PK1, and sample of participants in the survey at PK2 [17]. We then extended this analysis by performing a series of probit regressions where the probability of remaining in the study at each wave is modeled as a function of the baseline values of the following predictors [18]: age, race, social support, and whether the participant received welfare. To determine if non-response was missing completely at random (MCAR) we conducted Little's test to determine if non-response [19] and then for variables for which the MCAR assumption did not hold, we ran bivariate tests between the dependent and predictor variables to assess which variables accounted for the non-random missingness. For our primary analysis, rather than conducting a complete case analysis, we used a repeated measure mixed model, which can account for unbalanced data or data with missing within-person data. However, to test the sensitivity of our results to missing observations we also conducted sensitivity analysis with only the participants with matched coordinates and outcome measures at the baseline and first follow-up wave and found that our results were substantively unchanged.

Previous analysis of the RISK dataset by Arcaya et al., found that at the first follow-up wave, residents were essentially randomized to neighborhoods with respect to county sprawl [20]. We replicated this analysis with respect to gentrification by assessing the degree of neighborhood selection at the first follow-up wave and comparing the evidence of selection at follow-up to selection at baseline. To test this selection assumption, we fit a series of hierarchical bivariate linear regressions, regressing our gentrification index at each wave on predictors (age, race, gender, social support, welfare, education) from the previous wave. We report descriptive statistics for the full study population and tested for baseline imbalance in the covariates between the wave one follow up neighborhood categories.

We also conducted additional robustness checks. We tested for sensitivity to a mean rather than median household income ratio, specification of the self-rated health models as ordered logistic regressions, and including an additional time-specific effect for the second follow-up wave (2009). We tested if results were specific to living in New Orleans at follow-up by running models separately for those who moved back to New Orleans by 2006. Finally, we conducted a treatment on the treated effect, where we ran a simple longitudinal analysis controlling for gentrification at each stage of follow up, as well as potential confounders including baseline age, and race, and wave specific social support, welfare, employment and number of children, clustering participants in their baseline census tracts, and observations within participants.

Analyses were conducted using Stata 15.0 [21].

Results

Table 7 displays the baseline characteristics of all included participants, comparing the average or proportion of the population in each neighborhood category in the assigned first follow-up period. We did not include changes in outcomes between the baseline and the follow-up waves in the table but describe them here. The study population was young, with a mean age of 25 at baseline. The vast majority of the sample identified as non-Hispanic black (nearly 85%), and 10.5% identified as Non-Hispanic White. At baseline, most (84%) had at least a 12^{th}-grade education. Respondents had on average 1.8 children and enjoyed high levels of social support (mean 3.18). Only one in ten respondents received welfare or cash assistance at baseline, though all lived under 200% of the poverty level, and just over 50% were employed. The average BMI

at baseline was 28.36 kg/m^2 and increased by 1.34 points to 30.12 kg/m^2 by the second round of follow-up.

We found high rates of housing instability and mobility in the population: participants moved an average of 3.7 times in the four years after Katrina and an average of 3.65 times just during the first year after Katrina. Only 36%of respondents were living in their assigned neighborhoods by 2009, and 23% were living back in their Pre Katrina neighborhoods in 2009.

In 2003, a quarter of census tracts and 28% of participants lived in neighborhoods designated as gentrified between 1990 and 2000. By 2006, 18% of census tracts and 17% of participants resided in neighborhoods that gentrified between 2000 and 2006-2009. Though a smaller percentage of census tracts where respondents lived gentrified at the first follow-up wave than at baseline, on average respondents' neighborhoods in 2006 had more than $10,000 higher median household income incomes. This likely in part reflects the very low household incomes in New Orleans county in comparison counties where respondents were displaced to in 2006. We also found participants baseline neighborhoods underwent substantial gentrification between 2000 and the final year of the study period, 2009: 61% of the census tracts had more than a five percentage point change between 2000 and 2009 (2008-2012 ACS).

Assigned neighborhoods were substantially more racially diverse than baseline neighborhoods, and the assigned neighborhoods underwent changes in racial composition between 2000 and 2006. In the baseline neighborhoods in 2000, 60% of respondents lived in majority Black neighborhood, and 28% lived in majority White neighborhoods. Whereas, in assigned neighborhoods in 2006, 44% of respondents lived in majority Black neighborhoods and 22% lived in majority white neighborhoods. Between 2000 and 2006 the percentage of participants living in majority Black neighborhoods decreased by four percentage points and the

percent of respondents living in majority white neighborhoods increased by 17 percentage points.

Table 7: Baseline Characteristics for participants categorized by assigned (2006) neighborhood category

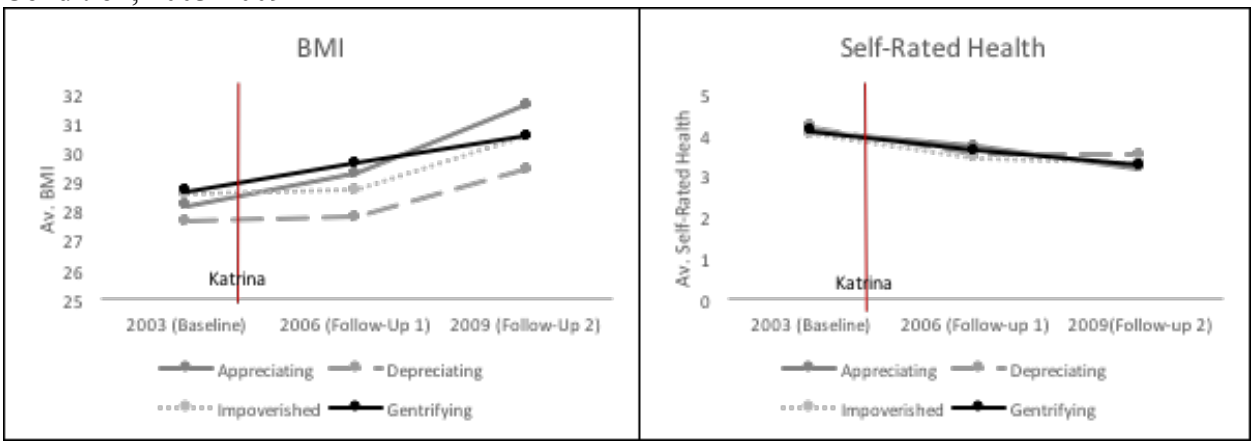
N=942	**Total Sample**						
	N	Mean (SD) or %	**Appreciating** Mean (SD) or %	**Depreciating** Mean (SD) or %	**Impoverished** Mean (SD) or %	**Gentrifying** Mean (SD) or %	P value/F-stat
Total Population	942		7.40%	25.40%	49.78%	17.42%	
BMI	899	28.36(7.02)	28.18 (6.2)	27.66(7.68)	28.57(7.04)	28.69(6.79)	0.501
General Health	924	4.09(0.84)	4.08(0.79)	4.21(0.85)	4.02(0.82)	4.09(0.82)	0.101
Age at baseline	942	25.26(4.49)	25.26(3.82)	25.73(4.98)	24.79(4.3)	25.28(4.38)	0.136
Number of Children*	938	1.81(1.03)	1.71(0.94)	1.78(1.05)	1.84(1.10)	1.79(0.85)	0.821
Social Support (1=low 4=high)*	906	3.18(0.45)	3.15(0.51)	3.24(0.42)	3.16(0.47)	3.23(0.47)	0.190
Race/Ethnicity							
NH White	65	9.43%	23.08%	d50.77%	15.38%	10.77%	
NH Black	597	86.65%	5.36%	22.45%	53.60%	18.59%	0.000
Hispanic/Other	27	3.92%	14.81%	29.63%	48.15%	7.41%	
Receipt of welfare or cash assistance	922	11.06%	5.66%	8.38%	15.80%	12.20%	0.036
Employed	940	51.49%	59.62	52.72%	49.68%	51.59%	0.602
Highest level of Education	929						
8^{th} grade	6	0.65%	0%	40.00%	20.00%	40.00%	
9^{th}grade	26	2.80%	10.53%	42.11%	42.11%	5.26%	
10^{th}	46	4.95%	5.71%	22.86%	54.29%	17.14%	0.528
11^{th}	67	7.21%	3.92%	33.33%	41.18%	21.57%	
12^{th}	784	84.39%	7.87%	24.79%	29.75%	17.59%	
Neighborhood Variables							
Racial Composition							
Majority White	308	38.5%	14.12%	37.79%	35.5%	12.6%	
Majority Black	351	43.88%	2.09%	19.7%	55.82%	22.39%	0.000
Majority Hispanic/ No majority	141	17.62%	7.5%	25.66%	49.23%	17.71%	

In Figure 3, we plot unadjusted time trends for average BMI and self-rated health at each of the data collection waves, and for each of the neighborhood categories. All data points use the

2006 “assigned” neighborhood categories. The black line represents gentrifying neighborhoods (the treatment), and the light grey dotted line represents continuously impoverished neighborhoods (the control).

Figure 3 shows that before Katrina average BMI was slightly higher in gentrifying neighborhoods than the other neighborhood types, though this difference was not significant. There is a slight upward trend in BMI after Katrina, though this is noticeable across all neighborhood types. The figure for self-rated health shows that trends in self-rated health did not differ appreciably across the neighborhood types, though there is a clear downward trend for all groups after Katrina, indicating worsening general health.

Figure 3: Unadjusted Trends in Average BMI and Self-Rated Health by neighborhood Condition, 2003-2009



*the red line represents hurricane Katrina.

Table 8 displays results from our main difference-in-differences analysis. The estimates showed evidence of no statistically significant changes in BMI or self-rated health related to neighborhood assignment, in models with and without adjustment for covariates. The coefficient for the interaction between post and gentrifying neighborhoods for self-rated health was close to zero for the adjusted and unadjusted (β=-0.04 and β =-0.07) analysis, suggesting there is no effect of gentrification on self-rated health in our population. The magnitude of effect for BMI

was also not significant in the unadjusted (β =0.18 CI: -1.49,1.14) or adjusted (β =1.12 CI:-2.74,0.49) analysis. Results were consistent when we adjusted for age, race, welfare status and social support in fully adjusted multivariable models. In the adjusted analysis we find that for respondents pre-Katrina, BMI was significantly higher in gentrifying (β =1.85 p<.05) neighborhoods in comparison to consistently impoverished neighborhoods. Our results were substantively unchanged when we included a time-specific effect, with two separate post-Katrina periods.

Table 8: Associations between Post-Katrina Gentrification, and BMI and Self-Rated health

	BMI		**Self Rated Health**	
	Model 1 β (95% CI)	Model 2[a] β (95% CI)	Model 1 β (95% CI)	Model 2[a] β (95% CI)
Pre-Katrina Impoverished	-	-	-	-
Pre-Katrina Appreciating	0.38 (-1.50,2.25)	2.41* (-0.08,4.91)	0.07 (-0.22,0.35)	0.14 (-0.25,0.53)
Pre-Katrina Depreciating	-1.05* (-2.21,0.10)	0.73 (-0.94,2.41)	0.20** (0.03,0.37)	0.22* (-0.03,0.48)
Pre-Katrina Gentrifying	0.16 (-1.16,1.47)	1.85** (0.03,3.68)	0.08 (-0.11,0.28)	0.18 (-0.11,0.46)
Post-Katrina Impoverished	-	-	-	-
Post-Katrina Appreciating	0.44 (-1.28,2.16)	-0.90 (-3.02,1.21)	-0.05 (-0.40,0.30)	0.16 (-0.29,0.61)
Post-Katrina Depreciating	0.35 (-0.70,1.40)	-0.16 (-1.58,1.27)	-0.06 (-0.27,0.15)	-0.12 (-0.41,0.18)
Post-Katrina Gentrifying	-0.18 (-1.49,1.14)	-1.12 (-2.74,0.49)	-0.04 (-0.29,0.21)	-0.07 (-0.40,0.26)

* p<0.10, ** p<0.05, *** p<0.01

a. adjusted for age, race, welfare receipt and social support at baseline.

We then examined whether participants of different races were differentially affected by gentrification. Only Whites had a significant (β=-5.94 CI:-11.72,-0.15; p<.05) relationship between

gentrification and BMI, which should also be interpreted cautiously given the multiple subgroups and outcomes we tested. The significant relationship, for respondents in the "other" racial category, who were living in gentrifying neighborhoods pre-Katrina, compared to continuously low-income neighborhoods, and BMI should similarly be interpreted cautiously.

Table 9: Associations between gentrification, and BMI and self-rated health, adjusted models and stratified by individual race

	BMI[a]			**Self-Rated Health[a]**		
	White β (95% CI)	Black β (95% CI)	Other β (95% CI)	White β (95% CI)	Black	Other
Pre-Katrina Impoverished	-	-	-	-	-	-
Pre-Katrina Appreciating	-1.71 (-9.40,5.98)	3.03** (0.02,6.05)	-2.16 (-7.33,3.00)	-0.05 (-1.30,1.21)	0.12 (-0.36,0.60)	0.09 (-0.84,1.01)
Pre-Katrina Depreciating	-3.36 (-10.20,3.48)	0.98 (-0.84,2.81)	-2.95 (-10.53,4.62)	0.12 (-0.99,1.24)	0.17 (-0.11,0.45)	0.79 (-0.39,1.97)
Pre-Katrina Gentrifying	3.16 (-4.67,10.99)	1.64 (-0.31,3.58)	-12.31** (-23.53,-1.09)	-0.29 (-1.59,1.01)	0.18 (-0.12,0.48)	0.65 (-1.04,2.34)
Post-Katrina Impoverished	-	-	-	-	-	-
Post-Katrina Appreciating	-3.30 (-9.21,2.61)	-1.25 (-3.81,1.31)	2.55 (-1.94,7.04)	0.76 (-0.52,2.05)	0.09 (-0.46,0.64)	0.79 (-0.32,1.90)
Post-Katrina Depreciating	-4.22 (-9.34,0.89)	0.18 (-1.42,1.78)	0.75 (-3.21,4.71)	0.33 (-0.80,1.46)	-0.07 (-0.39,0.26)	0.04 (-1.41,1.49)
Post-Katrina Gentrifying	-5.94** (-11.72,-0.15)	-0.91 (-2.68,0.87)	2.33 (-2.71,7.36)	1.14* (-0.20,2.47)	-0.14 (-0.50,0.21)	0.29 (-1.66,2.24)

* p<0.10, ** p<0.05, *** p<0.01

a. all models adjusted for age, welfare receipt and social support at baseline.

Finally, we examined whether neighborhood racial composition differentially affected individual outcomes. We find no differential effect post-Katrina of gentrification on either outcome, so fail to reject the null hypothesis that the effect of gentrification was the same for neighborhoods with majority white, majority black, or majority Hispanic/no majority. We do

however find that for respondents living in majority white neighborhoods pre-Katrina, BMI was significantly higher in gentrifying (β =3.01 CI: 0.13,5.89 p<0.05) and appreciating (β =2.96 CI: 0.13, 5.89 p<0.05) neighborhoods in comparison to consistently impoverished neighborhoods.

Table 10: Associations between post-Katrina gentrification, and BMI and self-rated health, adjusted models and stratified neighborhood racial composition

	BMI[a]			**Self-Rated Health**[a]		
	Majority White β (95% CI)	Majority Black β (95% CI)	Other[b] β(95%CI)	Majority White β(95%CI)	Majority Black β(95%CI)	Other[b] β(95% CI)
Pre-Katrina Impoverished	-	-	-	-	-	-
Pre-Katrina Appreciating	2.96** (0.13,5.80)	1.56 (-4.95,8.07)	0.69 (-6.88,8.26)	0.23 (-0.28,0.75)	0.07 (-0.86,1.00)	0.72 (-0.40,1.85)
Pre-Katrina Depreciating	0.26 (-2.04,2.56)	0.41 (-2.56,3.38)	1.94 (-2.09,5.98)	0.22 (-0.20,0.63)	0.38* (-0.03,0.78)	-0.10 (-0.69,0.50)
Pre-Katrina Gentrifying	3.01** (0.13,5.89)	1.16 (-1.79,4.12)	1.47 (-2.20,5.13)	0.14 (-0.37,0.65)	0.22 (-0.19,0.63)	0.13 (-0.42,0.67)
Post-Katrina Impoverished	-	-	-	-	-	-
Post-Katrina Appreciating	-0.75 (-3.59,2.10)	-0.60 (-5.93,4.73)	-1.48 (-6.17,3.21)	0.23 (-0.36,0.82)	0.15 (-0.96,1.25)	0.10 (-0.95,1.15)
Post-Katrina Depreciating	-0.16 (-2.46,2.15)	-0.15 (-2.36,2.05)	0.26 (-2.95,3.47)	-0.06 (-0.53,0.41)	-0.27 (-0.75,0.21)	0.27 (-0.37,0.91)
Post-Katrina Gentrifying	-1.68 (-4.74,1.38)	-0.55 (-2.69,1.59)	-1.57 (-4.21,1.07)	0.11 (-0.50,0.72)	-0.27 (-0.75,0.21)	0.19 (-0.38,0.76)

* p<0.10, ** p<0.05, *** p<0.01
a. adjusted for age, race, welfare receipt and social support at baseline.
b. Neighborhoods categorized as "Other" have majority Hispanic, or no majority population

ROBUSTNESS CHECKS

Appendix 4 Table 1 shows our analysis using 10% as the cutoff. Our results did not change substantively from using a five percentage point change as the as cut off, with the exception that neighborhoods that had no majority or majority Hispanic racial/ethnic

composition were associated with -2.43 ($p<.05$, CI: -4.29,-0.56) units lower BMI than neighborhoods with majority White or majority Black neighborhoods. Our results remained substantively unchanged when we categorized neighborhoods that experienced an increase in their relative income ratio as having gentrified, though a much larger percentage of neighborhoods (24.83% vs 17.71%) were categorized as gentrifying using the more lenient definition compared to the five percentage point definition.

We tested for selective attrition and non-response bias at the two follow-up waves, and found that gender was the only source of substantial selective attrition or non-response bias, so we replicate previous analysis using the RISK dataset [22], and drop all men from the analysis (N=77; 7.56% of the sample). Our final sample size includes 942 participants. Respondents lived in 256 census tracts across one state at baseline, at the first follow-up wave they lived in 26 states and 447 census tracts.

Neighborhood selection with respect to measured confounders and gentrification appears to be random. We find no evidence of significant selection associated with gentrification at follow-up. No measured variables were significantly associated with the gentrification index, though there was a marginally significant relationship (B=-0.12 p=0.057) between being non-Hispanic Black compared to non-Hispanic White, and living in a neighborhood that between 2000 and 2006 experienced a decrease in the census tract to county ratio of median household income. In Table 7, we showed the distribution of the participant characteristics between the four neighborhood types, and show that for most variables, there was participant balanced at baseline between the neighborhood types. We found evidence of imbalance on race and receipt of welfare at baseline and therefore included these variables in our main regression analysis. There was not

evidence of significant imbalance in social support using the five percentage point cutoff (p=0.190), but there was evidence of imbalance when using the ten percentage point cut off, suggesting there might be potential imbalance along this variable, and we therefore also included social support in the adjusted models. In our test of differential effects for those living back in New Orleans by 2006, we found no significant differences in effect size or significance between the population that returned to New Orleans by 2006, and those who remained elsewhere. We tested modeling self-rated health as continuous and ordered logistic [23]. Though ordered logistic models were a better fit to the data, for ease of interpretation we presented the linear regression as results did not differ based on model specification.

Discussion

Among a population of Hurricane Katrina survivors with high rates of housing mobility after the storm, gentrification was not associated with differential changes in self-rated health or BMI, with non-significant point estimates close to zero. We did find high levels of gentrification in our study sample. Only a quarter of residents were living in their Pre Katrina neighborhoods in 2009, while 61% of respondents' baseline neighborhoods gentrified between 2000 and 2009.

Using an intent-to-treat study design and differences-in-differences analysis we found no significant differences in health between participants living in gentrified neighborhoods compared with continuously impoverished neighborhoods. Across models, there was a negative, but non-significant, relationship between BMI and gentrification post-Katrina in comparison to continually impoverished neighborhoods, suggesting that if anything living in a gentrifying compared to a consistently impoverished neighborhood is associated with lower BMI, but that there is not evidence that this relationship is significant. In our adjusted model we found a

significant positive relationship between gentrification and BMI pre-Katrina, but importantly pre Katrina neighborhood assignment was not random, so there may have been systematic differences between neighborhood residents that account for the significant association between gentrification and BMI.

There are several possible explanations for our results showing no significant effects of gentrification on health. First, it is possible that we are underpowered to detect a real effect, as we have a relatively small sample size. However, our effect sizes, especially for self-rated health, were close to zero across models, and power was sufficient to show statistically significant associations between county sprawl and BMI, after adjustment for individual characteristics, in another study using the RISK dataset, which used an even smaller sample size (n=280) (M. Arcaya et al., 2014).

Second, it is possible that gentrification, as measured by change in the census tract to county median household income between 2000 and 2006, did not cause self-reported BMI or general health to change. Gentrification may also positively and negatively affect health, and the different directional effects may cancel out any net effect.

Third, it is possible that these findings are unique to BMI and self-rated health. For other outcomes, there may be a unidirectional impact that our measures of health are not capturing. For other outcomes, there may be a unidirectional impact that our measures of health are not capturing.

Other studies on gentrification and health have found disparate effects of gentrification on health, and a systematic review of studies on gentrification and health found that estimated effects varied by outcome, time period studied, and operationalization of gentrification [1]. However, these significant findings may, however, be due to selection effects, as only one of the

previous studies on the empirical relationship between gentrification and health used a study design that can remove potential selection bias [24]. Using an earthquake as an instrumental variable, Lee, 2010 found no significant effect of gentrification on crime or violent crime in low-income tracts but found that in the short term gentrification increased the number of assaults in moderate-income neighborhoods [24]. Given the contentious debates about the causal relationship between neighborhoods and health [25-27], and susceptibility of estimates to confounding by neighborhood selection, quasi-experimental designs represent a major methodological improvement to previous work

One potential limitation of our analysis is that the context of Hurricane Katrina may be unique and limit generalizability The overall shock and disruption of Hurricane Katrina, and forced displacement after the storm may have overwhelmed the effects of neighborhood socioeconomic and cultural transformation. African-American women, who made up the majority of our study population, experienced the most difficulty returning to their post Katrina homes: a study found that only 42% of African-American women returned in the year after Katrina, compared to 70% of all Whites [28]. In our study population, only 27% of respondents indicated that in 2009 to 2010 they lived in their Pre-Katrina home. Participants moved numerous times, on average four times in the five years after Katrina, and only 40% of participants stayed in their assigned neighborhoods. The high levels of mobility may have reduced any neighborhood effects, as research suggests that neighborhood exposures may need to accumulate over time to impact health [29]. These explanations indicate that while displacement after Hurricane Katrina serves as a useful tool to assess internal validity, by creating a natural experiment and opportunity for a quasi-experimental study, the external

validity of our findings is limited and should be cautiously extrapolated to gentrification that low-income populations are exposed to when natural disasters do not occur.

Tragically, natural disasters such as Katrina are increasing in frequency [30], and have in some cases also catalyzed neighborhood change, pushing out some residents and attracting others [24, 31]. Areas with more severe physical property damage are more likely to undergo change [32, 33] and because of preexisting social and economic inequalities, low-income areas are often disproportionately impacted by natural disasters [34], and have worse baseline health indicators [35]. Low-income groups are also slowest to return after catastrophes, and often have the most difficulty rebuilding because of in lower rates of investment in hazard mitigation such as natural hazard insurance [36], as well as more limited access to recovery resources and health care access [35, 37]. Studies after Katrina showed that low-income households were more likely to leave after the storm [38], and renters and blacks were less likely to return to their Pre Katrina homes [39, 40].

Exogenous shocks such as storms can exacerbate existing spatial inequality, as natural hazards differentially impact neighborhood change processes according to prior neighborhood characteristics [41]. While building resiliency to future storms is integral to the rebuilding process, respecting resident's right to remain and incorporating broad voices in the recovery planning should also be prioritized [28, 42, 43], as should minimizing rapid gentrification induced by a hazard. Broadly, proactive policies to build and rebuild affordable housing, and investing in community organizing social connections and anchor institutions can help residents remain in their neighborhoods and build resiliency and reduce vulnerability to future disasters. Further, to minimize recovery disparities after natural disasters, governments and emergency management professionals can more equitably distribute rehabilitation resources and bring low-

income and working-class voices into the recovery planning and process, to minimize recovery disparities.

LIMITATIONS

While our study represents a major methodological improvement on previous studies on gentrification and health, we mention several additional limitations. The near randomization in our sample improves our ability to make causal inference, and allows us to explore the effect of gentrification, net of selection into those neighborhoods. We control for individual-level covariates imbalanced at baseline, but it is possible that imbalance remained on unmeasured variables. Our differences-in-differences model also assumes that we can remove any unobserved time and neighborhood-specific effects, (parallel trends assumption), but the time-varying confounders may remain despite the robust study design.

Additionally, our measure of gentrification may be imprecise and may not be able to distinguish gentrification from other forms of neighborhood transition, as our measure relies on census data which only captures the socioeconomic characteristics of gentrification. Recognizing the limitation of census data, we nonetheless chose to use the census tract to median household income because it allowed us to compare geographies across the U.S., which was necessary given that our study participants were displaced to nearly 100 different counties across the country after Katrina. And, our use of census tract to median county income is a commonly used measure that correlated well with other indicators of gentrification (Bostic & Martin, 2003; Ding et al., 2015). Our measure of gentrification may also understate upgrading in neighborhoods where the whole metropolitan area is growing economically. However, given the period of study, which is at the peak of the financial crash and immediately after, this is unlikely to have

commonly occurred, and reports show that median household income did not grow in New Orleans between 2000 and 2010. Additionally, we tested several alternative specifications of our gentrification measure, and results were not sensitive to changes in the measure.

Our outcomes are self-reported which can potentially result in a social desirability bias or recall bias. However, it is unlikely this bias would occur differentially among participants based on the neighborhood of assignment and therefore should not impact the estimates. Finally, as mentioned earlier, our results also may not be generalizable, as the study cohort was drawn from a single geographic area, comprises mostly young, African-American, low-income mothers and all participants were exposed to a devastating Hurricane.

CONCLUSION

This article is, to our knowledge, only the second paper using a natural experiment to examine the relationship between a neighborhood exposure and individual health [20]. In this longitudinal quasi-experimental analysis using a unique dataset, we find that essentially random assignment post-Katrina to neighborhoods with varying levels of gentrification produced no detectable effects on health. While gentrification likely has numerous important social and economic effects, we do not find evidence for health impacts in this population of survivors of hurricane Katrina.

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