Health & Place xxx (xxxx) xxx

Contents lists available at ScienceDirect

Health and Place

journal homepage: http://www.elsevier.com/locate/healthplace

Effects of gentrification on health status after Hurricane Katrina

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ARTICLE INFO

Keywords:
Gentrification
Social determinants of health
Neighborhood
Urban development
Natural experiment
Multi-level analysis

ABSTRACT

Despite substantial debate about the impacts of gentrification on cities, neighborhoods, and their residents, there is limited evidence to demonstrate the implications of gentrification for health. We examine the impacts of gentrification on several health measures using a unique individual-level longitudinal data set. We employ data from the Resilience in Survivors of Hurricane Katrina (RISK) project, a study of low-income parents, predominantly non-Hispanic Black single mothers, who participated in a New Orleans-based study before and after Hurricane Katrina. After Katrina, all participants were displaced, at least temporarily, from New Orleans, and had little or no control over neighborhood placement immediately following the storm. This near-random displacement after Katrina created a natural experiment. We employ a quasi-experimental intent to treat design to assess the causal effects of gentrification on health in the RISK population. We do not find evidence of significant main effects of being displaced to a gentrified neighborhood on BMI, self-rated health, or psychological distress. The analysis employs a quasi-experimental design and has several additional unique features– homogeneous population, limited selection bias, and longitudinal data collection– that improve our ability to draw causal conclusions about the relationship between gentrification and health. However, the unique context of displacement by natural disaster may limit the generalizability of our findings to other circumstances or residents experiencing gentrification.

1. Introduction

Socioeconomic and racial disparities in health in the US are geographically patterned (Diez Roux, 2001; Macintyre et al., 2002). Exposure to neighborhood disadvantage, particularly concentrated poverty and segregation, contributes to a broad range of negative health outcomes, including elevated BMI (Corral et al., 2015), blood pressure (Chaix et al., 2009), heart disease (Jones, 2013), and preterm birth (Britton and Shin, 1982) and premature mortality (Subramanian et al., 2005). Although research has established robust associations between area economic deprivation and worse population health outcomes (Robert, 1999; Vos et al., 2014), there is limited research about how changes in the demographic, social, and cultural context of a neighborhood affect health outcomes (Schnake-Mahl et al., 2019). Previous studies have explored contemporaneous and lagged health effects of neighborhoods in general (Ellen et al., 2001), how individuals changing neighborhoods affects their health (Ludwig et al., 2011), and how health can impact neighborhood selection (Arcaya et al., 2014a; James et al., 2015). However, there is limited knowledge of how socioeconomic and cultural changes *within* a neighborhood causally affect residents' health. In part, this is because it is difficult to show that neighborhood changes *cause* changes in health, because low-income populations are more likely to have poorer health to begin with, and are more likely to live in more resource-deprived neighborhoods compared to more affluent populations (Ellen and Glied, 2015).

Gentrification – a process of demographic, social, cultural and political change - is one form of neighborhood change. Though there is substantial debate on the definition of gentrification (Slater, 2006; Brown-Saracino, 2013; Lees et al., 2013), we define gentrification as the process whereby neighborhoods that have undergone disinvestments

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https://doi.org/10.1016/j.healthplace.2019.102237
Received 5 March 2019; Received in revised form 9 October 2019; Accepted 21 October 2019
Available online 15 November 2019
1353-8292/

and economic decline experience a reversal, reinvestment, and the in-migration of a relatively well-off population (Smith, 1998). Though prevalent in the 1990s in many central-city neighborhoods, since 2000 gentrification processes have occurred at faster rates and across a greater number of neighborhoods and areas (Hwang and Lin, 2016). Despite the recent proliferation of gentrification, there is limited evidence on whether gentrification matters for health (Venis Wilder et al., 2017). And, the available literature are mostly from observational studies lacking the methodological rigor to draw causal inferences (Schnake-Mahl et al., 2019). In this article, we explore a methodology that limits selection into neighborhoods via quasi-experimental design and multivariate hierarchical analysis, and measure various associations between neighborhood gentrification, and self-rated health, BMI, and psychological distress.

This study uses data from the Resilience in Survivors of Katrina (RISK) project, a longitudinal study of 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 2009–2010, after Katrina (2005) to track participants across neighborhoods. Katrina displaced all participants, at least temporarily, from New Orleans. About half returned to their pre-Katrina parish in subsequent years, and residents had little or no control over neighborhood placement immediately following the storm (Arcaya et al., 2014b). This near-random displacement after Katrina created a natural experiment, which we use in our study design.

To identify how health outcomes would have evolved in the absence of gentrification, we employ a differences-in-differences approach. We compare health outcomes among those displaced into neighborhoods that underwent gentrification between 2000 and 2005–2009, with those displaced to low-income communities that did not experience gentrification.

Gentrification may have both positive and negative effects on health (Venis Wilder et al., 2017; Formoso et al., 2010). As higher income residents move in and neighborhoods gain investment, residents' health may improve due to factors such as, more health promoting built environment factors, greater access to healthy food options and opportunities for physical activity, and additional local economic opportunity (Meltzer, 2016). For residents displaced to neighborhoods undergoing gentrification, such as those in our study, further housing instability and the risk of secondary displacement, due to increasing housing prices, may exacerbate already stressful situations (Kawachi et al., 2014; Fullilove, 1996; Desmond and Kimbro, 2015). And, existing increased competition for low-income housing and low-wage labor may limit the receptivity of gentrifying neighborhoods to new residents. Further, the disruption to community-based organizations and political power, as a consequence of gentrification, may make integration into new neighborhoods more difficult, and both formal and informal resources more challenging to access than in stably low-income neighborhoods. The effects of gentrification may vary by individual characteristics that influence the ease with which people can find alternative housing or the extent to which residents are connected to a neighborhood. These characteristics could include race, sex, age, income, length of the time in a neighborhood, and more.

Our research aims to contribute to the urban health literature by assessing the causal effects of place on health, using a quasi-experimental design to examine displacement to neighborhoods of differing socioeconomic trajectories in the aftermath of a disaster. We hypothesize that being assigned to a neighborhood that underwent gentrification, in comparison to a persistently poor neighborhood, will predict worse health outcomes. We suggest that the adverse factors of being displaced to a gentrifying neighborhood will outweigh the potential benefits of increased investment and influx of higher SES residents (Venis Wilder et al., 2017). Studies also suggest that neighborhood racial stratification shapes the trajectory and implications of gentrifying neighborhoods (Anderson and Sternberg, 2013; Hwang and Sampson, 2014), and we explicitly test for effect modification by individual race and neighborhood majority racial composition in our analysis.

2. Methods

2.1. Data source

Data comes from the RISK project, a longitudinal qualitative and quantitative study of 1019 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 18-34 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 and followed respondents to their new neighborhoods. Three follow-up waves have been conducted since then, though we only included the first two follow-up waves: 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," 2006–2007 as "first follow-up wave," and 2009–2010 as "second follow-up wave." The most recent study wave was not analyzed here because data collection was not completed until 2018 after analysis for this article was conducted. We coded all residences to census tracts, and the Princeton and Harvard Institutional Review Boards approved the study.

2.2. Study design

We took advantage of the near-random post-Katrina assignment to neighborhoods, present in our study sample (Arcaya et al., 2014b). We employed a quasi-experimental Intent-To-Treat (ITT) approach to analyze the relationship between gentrification in neighborhoods of assignment post-Katrina (2006), and health. We analyzed participants 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. Our primary analysis employed a differences-in-differences (DD) method to compare self-rated health, psychological distress, and BMI among those assigned to a gentrified neighborhood versus assigned to a persistently poor neighborhood (first difference) before and after Katrina (second difference). Our study design and analysis method avoid 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.

2.3. Outcomes

We examined three outcomes: self-rated health (SRH), Body Mass Index (BMI), and a measure of general psychological distress. BMI appears to vary with the degree of neighborhood disadvantage and environment (Mujahid et al., 2008; Robert and Reither, 2004; Ruel et al., 2010), suggesting that as neighborhood context changes, BMI changes as well. Using the RISK dataset, Arcaya et al. showed that BMI varied with change in sprawl (Arcaya et al., 2014b), supporting the potential for BMI to also change with change in gentrification. BMI (Kg/m^2), was calculated at each wave from self-reported weight (kg) divided by the square of height (m2) and was measured as continuous.

Self-rated health is affected by and sensitive to social factors (Prus, 2011), is a widely used indicator of general health, and is strongly associated with subsequent mortality and various measures of mental and physical morbidity (Finch et al., 2002; Idler et al., 2000; Jylhä, 2009). Gibbons et al., found that for SRH, White gentrification had no

measurable effect, but Black gentrification had differential effects (Gibbons and Yang, 2014). We used a measure of SRH which asked respondents to rate their health on a 5-point Likert scale, with lower scores indicating worse health. We modeled SRH as a continuous variable (Schnittker and Bacak, 2014), but also tested sensitivity to measurement as a dichotomous (fair/poor) or ordinal outcome.

We employed the Kessler Psychological Distress Scale (K6), a widely used six-item screening measure for non-specific psychological distress (Kessler et al., 2003). The scale has strong psychometric properties (Furukawa et al., 2003) and has been previously used to measure psychological functioning among survivors of Hurricane Katrina (Galea et al., 2007). Participants were asked to rate items (e.g., "During the past 30 days, about how often did you feel so depressed that nothing could cheer you up?") on a 5-point Likert-type scale ranging from 0 (none of the time) to 4 (all the time), and all scores were summed to generate a zero to twenty-four-point continuous measure, with higher scores representing greater psychological distress (Fussell, 2012; Mitchell and Beals, 2011; Mewton et al., 2016). We tested inclusion of the Kessler scale as continuous, categorical, and binary variable types. For the categorical variable, scores of 0–7 indicated probable absence of mental illness, 8–12 probable mild or moderate mental illness, and 13 and above probable serious mental illness (SMI). For the binary variable, scores of 13 and above indicated those with probable SMI, and below 13 indicated those without SMI (Kessler et al., 2003).

2.4. Exposure conceptualization

We utilized a relative measure of income to account for differences in wage levels across counties and years (Rosenthal, 2008; Ellen and O'Regan, 2008). Researchers have operationalized gentrification in various manners, including increases in the following: household income, housing cost, percent White population, and percent college-educated, in formerly low-income neighborhoods. Our measure of gentrification uses median income growth (Ellen and O'Regan, 2008; McKinnish et al., 2010; Landis, 2016). This measure is attractive because 1) it uses administrative data that is available across the US at the census tract level; 2) other studies found that this index correlated well with other metrics including, educational up-skilling, racial turnover, and housing rents (Lee and Lin, 2018); and 3) it produces similar results to more complex indices (Bostic and Martin, 2003; Ding et al., 2015). Our neighborhood trajectory variable incorporates our measure of whether a neighborhood was low-income in the baseline year. Inclusion of the low-income requirement helps to distinguish gentrifying neighborhoods from moderate or high-income neighborhoods that experience further economic ascension. Many neighborhoods in the New Orleans metropolitan area met this low-income requirement before Katrina. While gentrification is often conceptualized as an urban process, suburban gentrification is an emerging phenomenon among suburban low-income areas (Markley, 2018; Charles, 2013). We therefore also include respondents living in suburban areas before Katrina, rather than limiting our study to only those living in cities.

A final advantage of our coding is that we do not assume a linear relationship between change in neighborhood economic status and resident health. Instead, the categorical variable creates a clear reference group, allowing us to compare gentrifying neighborhoods to continuously low-income neighborhoods.

3. Exposure measurement

We operationalized neighborhoods using census tracts boundaries. Though imperfect representations of neighborhoods, census tracts are the most commonly used administrative unit in multilevel neighborhood health studies (Arcaya et al., 2016). There is also evidence suggesting census tracts perform well for health research (Krieger et al., 2003), and many other gentrification studies have employed these geographies (Hwang and Sampson, 2014; Ellen and O'Regan, 2008; McKinnish et al., 2010). We clustered participants in baseline census tracts, as neighbors were more likely to share sociodemographic profiles because of previous selection into neighborhoods. All participants were geocoded to census 2000 tract boundaries, and 2010 census tract boundaries were normalized to 2000 census tract boundaries using the Longitudinal Tract Base (Logan et al., 2014).

We created a neighborhood change index based on the change in the ratio of the median household income in the census tract to the county median household income, using decennial census and 2005–2009 ACS 5-year estimate data. For baseline, we subtracted the ratio in 2000 from the ratio in 1990, and for follow-up waves we subtracted the ratio in 2005–2009 from the ratio in 2000, to represent a change in ratios between time periods. We then use the neighborhood change index to create four categories representing four types of neighborhood: gentrifying, persistently poor, appreciated, and depreciated.

Following the methods laid out by Ellen and Regan (2011), we only categorized census tracts that in 2000 were low-income– defined as those neighborhoods with median household incomes in the bottom 40th percentile of the county median income– as eligible to gentrify (Ellen and O'Regan, 2011). We categorized all other neighborhoods as "affluent," though many of these neighborhoods were either moderate or high income. Then, within the low-income pool of neighborhoods, we identified census tracts where there was a five-percentage- point or more change in the gentrification index (Ellen and O'Regan, 2011), and categorized those neighborhoods as gentrifying. We created three other mutually exclusive neighborhood trajectories based on the index of census tract to county median household income and whether the neighborhood was low-income in the base year. Other studies have similarly created categorical variables that include a gentrification category to represent various socioeconomic trajectories neighborhoods can take (Ding et al., 2015; Gibbons et al., 2016; Williams; Huynh and Maroko, 2014). See Table 1 for descriptions of the neighborhood trajectory variable categories.

3.1. Covariates

3.1.1. Neighborhood level covariates

We considered the racialized implications of gentrification using three variables. Evidence suggests race powerfully impacts neighborhood selection and shapes patterns of segregation and risk of neighborhood disinvestment and investment (Charles, 2003). Previous research has found that neighborhood racial segregation predicts higher risk of neighborhood gentrification (Hwang and Sampson, 2014) and is associated with both BMI (Corral et al., 2015) and self-rated health (Gibbons and Yang, 2014) among Blacks. We use racial/ethnic composition to assess the potential differential effects of gentrification by racial segregation. We calculated our measure as the 2006 racial/ethnic composition for the follow-up neighborhoods, and categorized neighborhoods based on the majority (>50%) racial/ethnic population (Papachristos et al., 2011), grouping majority Hispanic neighborhoods

Table 1
Neighborhood trajectory variable.

Gentrifying	Low-income[a] in 2000, and the ratio of neighborhood (census tract) to county household median income increased by five or more percentage points between 2000 and 2005–2009.
Persistently Poor	Low-income in 2000, and the ratio of neighborhood to county household median income either decreased, or increased by less than five percentage points between 2000 and 2005–2009.
Appreciated	Affluent in 2000, and the ratio of neighborhood to county household median income increased by five or more percentage points between 2000 and 2005–2009.
Depreciated	Affluent in 2000, and the ratio of neighborhood to county household median income either decreased, or increased by less than five percentage points between 2000 and 2005–2009.

[a] Low-income defined as census tracts with household median incomes in the bottom 40th percentile of county median incomes.

with those with no majority racial/ethnic composition (Hwang and Sampson, 2014). We assessed differences in neighborhood racial composition in 2006, for neighborhoods assigned post-Katrina. Our quasi-experimental design reduces the risk of neighborhood selection by race, so we did not adjust for potential confounding by residential segregation before Katrina. Instead, we ran our adjusted models separately for each of our neighborhood composition categories. Stratified analysis allowed us to test for differential impacts of gentrification based on the racial composition in the neighborhood and helped identify the possible unequal consequences of reinvestment based on the racial composition of communities (Papachristos et al., 2011).

3.1.2. Individual covariates

We included individual race/ethnicity (White, Black, Other) as a covariate to adjust for baseline imbalance between the treatment (i.e. displaced to a gentrifying neighborhood) and control (i.e. displaced to a non-gentrifying neighborhood) groups. We tested for potential differential effects of gentrification on participants of different races by running adjusted models separately for each of our racial categories. We additionally adjusted for welfare, which was imbalanced between the various exposure categories at baseline; a significantly greater percentage of those receiving welfare lived in persistently poor neighborhoods in comparison to appreciating or depreciating neighborhoods. We tested for but found no evidence of imbalance along additional demographic characteristics (see Table 2). We included age because it controls for time-specific effects. We also included social support as a covariate because studies have found a relationship between social support and various measures of health, and because participants with higher levels of social support may have had more choice in where to live (Arcaya et al., 2014b; Chan et al., 2015). We measured age as continuous; race as categorical (Non-Hispanic White, Non-Hispanic Black, Other race/-ethnicity, which included Asian and Hispanic); receipt of welfare or cash assistance as binary; and social support as continuous, using a validated four-point scale of social support (Cutrona and Russell, 1987).

3.2. Model building

3.2.1. 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, self-rated health, and psychological distress) over time. We clustered observations repeated over time (L1), for participants (L2), nested in neighborhoods (L3).

Using likelihood ratio tests for nested models, and Akaike information criterion and Bayesian information criteria for non-nested models, we tested the appropriateness of the multilevel (one versus two, and two versus three levels) data structure. We found the three-level model best fit the data. We used a repeated measure mixed-model, rather than conducting a complete case analysis, which accounts for unbalanced data structure and missing within-person data, for example, members missing data for the 2006 wave.

Our baseline model was a three-level model, with all three 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 persistently poor neighborhoods 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^2_{v0} as the between neighborhood variation in self-reported health, σ^2_{u0} as the between individual, within neighborhood variation in self-reported health, and σ^2_{e0}as the within neighborhood, within individual, between wave variation in self-reported health. We model the covariance as identity because we employed 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 also tested creating a categorical variable for waves, comparing the 2006 and the 2009 waves to the reference wave (2003). The *treatment* variable–the four-level categorical variable that indicated whether, between 2003 and 2006 the post-Katrina

Table 2
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 %	**Persistently Poor** 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)	0.509
Self-Rated Health(1 = high 5 = low)	924	4.09(0.84)	4.08(0.79)	4.21(0.85)	4.02(0.82)	4.09(0.82)	0.101
Psychological Distress (0 = low 24 = high)	898	4.9(4.13)	5.84(4.73)	4.61 (3.72)	4.94(3.98)	4.82(4.44)	0.301
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%	50.77%	15.38%	10.77%	0.000
NH Black	597	86.65%	5.36%	22.45%	53.60%	18.59%	
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						
8th grade	6	0.65%	0%	40.00%	20.00%	40.00%	0.528
9thgrade	26	2.80%	10.53%	42.11%	42.11%	5.26%	
10th	46	4.95%	5.71%	22.86%	54.29%	17.14%	
11th	67	7.21%	3.92%	33.33%	41.18%	21.57%	
12th	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%	

assignment neighborhood gentrified, was persistently poor, appreciated, or depreciated–was included as three dummy variables with persistently poor 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 a persistently poor neighborhood) post-Katrina. Our baseline model for the effect of gentrification on self-rated health is specified below. We repeated this model for the other outcomes, after adjustment for potential confounders, and conducted stratified analysis for individual race/ethnicity and neighborhood racial/ethnic composition. We test multiple hypotheses increasing the probability of a false positive. We therefore suggest caution in interpreting a single hypothesis as significant, when the majority of other results are not consistent with this result.

$$\begin{aligned} Self-Rated\ Health_{2ijk} = {} & \beta_0 + \beta_1 Post_{ij} + \beta_2 Gentrified_k + \beta_3 Depreciated_k \\ & + \beta_4 Appreciated_k + \beta_5 Post_{ij}{}^{*} Gentrified_k \\ & + \beta_6 Post_{ij}{}^{*} Depreciated_k + \beta_7 Post_{ij}{}^{*} Appreciated_k \\ & + (e_{0ijk} + u_{0jk} + v_{0k}) \end{aligned}$$

$$e_{0ijk} \sim \&doublehyphen; 6ptN(0, \sigma^2_{e0})$$

$$u_{0jk} \sim \&doublehyphen; 6ptN(0, \sigma^2_{u0})$$

$$v_{0k} \sim \&doublehyphen; 6ptN(0, \sigma^2_{v0})$$

3.2.2. Sensitivity analysis

3.2.2.1. Selective attrition and missingness. To look for evidence of selective attrition, we compared mean demographics at baseline, among the full sample, sample of participants in the survey at the first follow-up wave, and sample of participants in the survey at the second follow-up wave (Contoyannis et al., 2004). We then extended this analysis by performing a series of probit regressions where the probability of remaining in the study at each wave was modeled as a function of the baseline values of the following predictors (Miller et al., 2007): 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 (Little, 1988) and 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. To test the sensitivity of our results to missing observations, we also conducted analysis with only the participants with matched coordinates and outcome measures at the baseline and first follow-up wave.

3.2.2.2. Randomization analysis. Evacuation and resettlement location choices post-Katrina were constrained for low-income populations, and widespread damage from the storm likely increased the likelihood that people moved longer distances, away from damaged areas (Landry et al., 2007). News reports from the years after Katrina suggest that, particularly for low-income populations like those in our study, evacuees initially settled in areas where government-chartered buses or planes stopped (Tizon and Smith, 2005). 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 (Arcaya et al., 2014b). 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. 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.

3.2.2.3. Alternative exposure specification. For our exposure variable, we tested a three-level categorical variable that combined the appreciated and depreciated ("affluent" in 2000) categories. To test for sensitivity to the cut-off threshold, we replicated 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 gentrification index, a ten percentage point increase in the gentrification index, and any positive change in the gentrification index. We ran our models defining majority racial composition using a 40% rather than 50% threshold as well. We tested for sensitivity to a mean rather than median household income ratio, specification of the self-rated health and psychological distress models as ordered logistic and logistic regression, and inclusion of an additional time-specific effect for the second follow-up wave (2009). We examined 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.

We tested the impact of urbanicity by including a variable for urban versus suburban and rural areas, derived from the 2006 NCHS urban–rural classification scheme (Ingram and SJ, 2012), and matched to participants Wave 1 county assignments. The classification scheme includes the following categories: large central metro, medium metro, small metro, large fringe metro, micropolitan, and non-core areas. While we hoped to isolate impacts of suburban areas by separating our geographic indicator into three categories—urban, suburban, and rural—only one participant was displaced to a non-core, equivalent to rural, area. We instead combine large fringe metros, micropolitan and non-core areas into a single non-urban group, and combine large central metros, medium metros, and small metros into our urban category. We test inclusion of this urbanicity variable in our unadjusted and adjusted models, and stratify analysis to test for differential impacts of displacement to gentrifying neighborhoods in urban versus non-urban area.

Finally, we conducted a treatment-on-the-treated (TOT) effect estimate. We allowed exposure to move with respondents by running 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. We also conduct a sub group analysis, limiting the sample to those participants who remained in their 2006-assigned neighborhoods throughout the study period.

Analyses were conducted using Stata 15.0 (Stata Statistical Software, 2017).

4. Results

4.1. Participant characteristics

Table 2 displays the baseline characteristics of all included participants, comparing the average or proportion of the population in each neighborhood category in the assigned neighborhoods. Our final sample size included 942 participants. Respondents lived in 256 census tracts across one state at baseline, and at the first follow-up wave, they lived in 447 census tracts across 26 states. 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 87%), and 9.4% identified as Non-Hispanic White. At baseline, most (84%) had at least a 12th-grade education. Respondents had, on average, 1.8 children and enjoyed high levels of social support (mean 3.2). 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. Average reported monthly income increased by nearly $1,000 over the study period, from a mean of $1585 at baseline, to $2,600 by the second round of follow-up. At baseline, none of the health measures differed significantly between the neighborhood trajectories. The average BMI at baseline was 28.36 kg/m^2 and increased by 1.34 units–30.12 kg/m^2 by the second

round of follow-up, and the average response on the psychological distress measure rose from 4.9 to 5.6 showing increasing levels of distress. The average self-rated health declined from 4.1 to 3.3, and the proportion of respondents reporting poor or fair health increased from 3% to 23%, indicating worsening general health over time.

4.2. Participants' neighborhood and housing characteristics

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 during just the first year post-Katrina. Only 36% of respondents were living in their neighborhoods of initial displacement by 2009–2101, and 23% were living back in their pre-Katrina neighborhoods in 2009–2010.

Table 3 shows the timing of survey waves and exposure measurement and percent of the population in each neighborhood exposure category at each wave. 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 2005–2009. 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 incomes. This likely in part reflects the very low household incomes in New Orleans county in comparison to counties where respondents were displaced to in 2006. We also found participants' baseline neighborhoods underwent 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.

4.3. Trends in BMI, self-rated health, and psychological distress

In Fig. 1, we plot unadjusted time-trends for average BMI, self-rated health, and psychological distress at each of the data collection waves, and 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 persistently poor neighborhoods (the control). Fig. 1 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. There is a clear downward trend for all groups after Katrina, indicating worsening general health. For psychological distress, rates are non-significantly higher in appreciating neighborhoods at baseline, increase for all neighborhood trajectories by the first follow-up wave, and then for all neighborhood trajectories except appreciating, fall slightly by the second wave.

Table 3
Survey waves, exposure distribution, and time periods.

Wave	Baseline (Pre-Katrina)	First Follow-up Wave	Second Follow-up Wave
# of respondents [a]	947	667	702
Data collection time-period	2003–2004	2006–2007	2009–2010
Exposure time-period	1990 to 2000	2000 to 2005–2009	2000 to 2009–2012[a]
% population by neighborhood			
% persistently poor	18.3%	49.2%	47.0%
% appreciated	20.8%	7.3%	22.2%
% depreciated	33.2%	25.6%	47.03%
% gentrifying	28.4%	17.7%	19.6%

[a] In our main ITT analysis exposure remains in the first follow up wave, though we also test separating out the first and follow-up exposure waves b. Excludes males.

4.4. Associations between gentrification and health

Table 4 displays the results from our main difference-in-differences analysis. Crude and covariate-adjusted models alike showed no evidence of significant changes in BMI, self-rated health, or psychological distress related to gentrification. The coefficient for the interaction between post-Katrina 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 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 for BMI, or for the unadjusted (β- 0.06 CI:-1.26,1.15) or adjusted (β = 1.07 CI: -3.94, 2.54) analysis of psychological distress. The direction of the effect for psychological distress in gentrifying neighborhood post-Katrina switched from negative to positive after adjustment but remained non-significant in both analysis.

4.5. SUB group analysis

We then examined whether participants of different races were differentially affected by gentrification (Table 5). Among White respondents, living in a neighborhood that gentrified was associated with lower BMI (β=-5.94 CI:-11.72,-0.15; $p < 0.05$) and self-rated health (β=1.14 CI:-0.20, 2.47, $p < 0.10$). The significant BMI finding should be interpreted cautiously given the multiple subgroups and outcomes we tested.

Finally, we examined whether neighborhood racial composition differentially affected individual outcomes (Table 6). We found that respondents living in majority Black gentrifying neighborhoods compared to persistently poor neighborhoods had significantly higher levels of psychological distress (β = 2.15 CI: 1.25, 4.18, $p < 0.05$). But again, given the multiple subgroups tested this result could be a false positive so should be interpreted cautiously. For BMI and self-rated health, we found no differential effect post-Katrina of gentrification, so fail to reject the null hypothesis that the effect of gentrification was the same for neighborhoods with different majority racial/ethnic compositions.

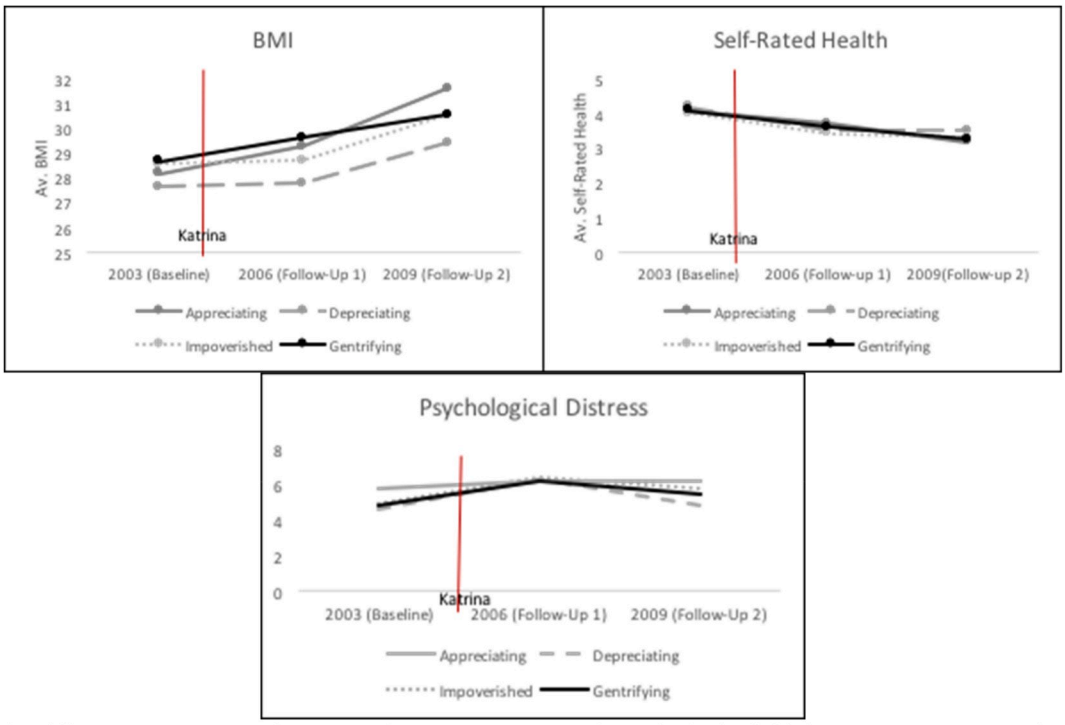
4.6. Robustness checks

4.6.1. Selective attrition and non-response

We tested for selective attrition and non-response bias at the two follow-up waves. We found that gender was the only source of substantial selective attrition or non-response bias, so we replicate previous analysis using the RISK dataset (Lowe et al., 2015), and dropped all men from the analysis (N = 77; 7.56% of the sample). Our results were substantively unchanged when we included only participants with matched coordinates at all study waves.

4.6.2. Randomization analysis

Neighborhood selection with respect gentrification appeared to be effectively random. We found 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 ($\beta = -0.12$ $p = 0.057$) 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 1, we showed the distribution of the participant characteristics between the four neighborhood types, and show that for most variables, there was participant balance at baseline. We found evidence of imbalance on race and receipt of welfare at baseline and therefore included these variables in our main regression analysis.



*red line represents Hurricane Katrina. a. For BMI and psychological, higher scores correspond with worse outcomes; for self-rated health, lower scores correspond with worsening health

Fig. 1. Unadjusted trends in average BMI, self-rated health, and psychological distress by neighborhood condition, 2003–2009*red line represents Hurricane Katrina. a. For BMI and psychological, higher scores correspond with worse outcomes; for self-rated health, lower scores correspond with worsening health. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 4
Associations between Post-Katrina Gentrification, and BMI, Self-rated health, and psychological distress.[a].

	BMI		Self Rated Health		Psychological Distress	
	Unadjustedβ (95% CI)	Adjusted[b]β (95% CI)	Unadjustedβ (95% CI)	Adjusted[b]β (95% CI)	Unadjustedβ (95% CI)	Adjusted[b] β(95% CI)
Post-Katrina Persistently Poor	Ref	Ref	Ref	Ref	Ref	Ref
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)	−0.50 (−2.17,1.17)	−0.59 (−2.56, 1.37)
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)	−0.13 (−1.14,0.89)	0.01 (−1.3, 1.31)
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)	−0.06 (−1.26,1.15)	1.07 (−3.94,2.54)

*p < 0.10, **p < 0.05, ***p < 0.01.
[a] For BMI and psychological, higher scores correspond with worse outcomes; for self-rated health, lower scores correspond with worsening health.
[b] Adjusted for age, race, welfare receipt and social support at baseline.

Table 5
Associations between gentrification, and BMI, self-rated health, and psychological distress,[a] adjusted models and stratified by individual race.

	BMI[b]			Self-Rated Health[b]			Psychological Distress[b]		
	Whiteβ (95% CI)	Blackβ (95% CI)	Otherβ (95% CI)	White β (95% CI)	Black	Other	White β (95% CI)	Black	Other
Post-Katrina Persistently Poor	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
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)	−1.95 (−8.23,4.34)	−0.34 (−2.71,2.03)	−1.53 (−7.18,4.13)
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)	−3.45 (−8.99,2.09)	0.29 (−1.15,1.72)	0.82 (−5.95,7.60)
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)	−0.12 (−6.51,6.27)	1.13 (−0.40,2.67)	−2.93 (−11.95,6.09)

*p < 0.10, **p < 0.05, ***p < 0.01.
[a] For BMI and psychological, higher scores correspond with worse outcomes; for self-rated health, lower scores correspond with worsening health.
[b] All models adjusted for age, welfare receipt and social support at baseline.

Table 6
Associations between post-Katrina gentrification and BMI, self-rated health, and psychological distress,[a] adjusted models and stratified neighborhood racial composition.

	BMI[b]			Self-Rated Health[b]			Psychological Distress[b]		
	Majority White β (95% CI)	Majority Black β (95% CI)	Other[c] β(95% CI)	Majority White β(95%CI)	Majority Black β(95%CI)	Other[c] β(95% CI)	Majority White β(95%CI)	Majority Black β(95%CI)	Other[c] β(95% CI)
Post-Katrina Persistently Poor	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
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)	−0.39 (−2.97,2.18)	−1.75 (−6.47, 2.98)	−1.78 (−7.58, 4.01)
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)	−0.75 (−2.82, 1.31)	1.26 (−0.81, 3.33)	−0.98 (−4.4, 2.4)
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)	−0.56 (−3.27, 2.16)	2.15** (1.25, 4.18)	1.07 (02.11, 4.25)

*p < 0.10, **p < 0.05, ***p < 0.01.
[a] For BMI and psychological, higher scores correspond with worse outcomes; for self-rated health, lower scores correspond with worsening health.
[b] Adjusted for age, race, welfare receipt and social support at baseline.
[c] Neighborhoods categorized as "Other" have majority Hispanic population, or no majority population.

4.6.3. Alternative exposure specifications

Our results did not change substantively using various cut off points for our gentrification index nor for a binary exposure measure. Using a ten percentage point cut-off rather than a five percentage point change as the cut off, we found that neighborhoods that had no majority or majority Hispanic racial/ethnic composition were associated with −3.09 ($p < 0.05$, CI: 5.82,-0.37) units lower BMI than neighborhoods with majority White or majority Black neighborhoods after Katrina. Applying a 40% threshold for majority racial composition did not substantively change our results, nor did categorizing 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. Our results were substantively unchanged when we included a time-specific effect, with separate 2006 and 2009 post-Katrina periods. Associations between neighborhood conditions and health were substantively unchanged with the addition of an urbanicity variable, whether the urbanicity indicator was included in the null model, adjusted model, or model stratified by geography.

4.6.4. Alternative model specifications

In our test of differential effects for those living back in New Orleans by 2006, we found no differences in effect size or significance between the population that returned to New Orleans by 2006, and those who remained elsewhere.

We also tested modeling self-rated health as continuous and ordered logistic, and psychological distress as ordered logistic and binary (Arcaya et al., 2018). Though ordered logistic models were a better fit to the data for self-rated health, for ease of interpretation we presented the linear regressions, as results did not differ based on the model specification or outcome type. The subgroup analysis, limited to the 40% of the population who remained in their 2006-assigned neighborhood, did not show different outcomes from our main analysis. Finally, our TOT analysis, allowing the exposure to move with residents, did not substantively differ from our main intent-to-treat analysis.

5. Discussion

Among a population of Hurricane Katrina survivors, displacement to a gentrifying neighborhood was not associated with differential changes in self-rated health, psychological distress, or BMI, with non-significant point estimates close to zero in unadjusted and adjusted analysis. Using an intent-to-treat study design and differences-in-differences analysis we found no significant health effects for participants who were displaced to gentrified neighborhoods compared to those displaced to persistently poor neighborhoods. Across models, there was a negative but non-significant relationship between BMI and gentrification post-Katrina in comparison to persistently poor neighborhoods. Suggesting that if anything, being displaced to a gentrifying compared to a persistently poor neighborhood is associated with lower BMI, but that there is no evidence that this relationship is significant. In our subgroup analysis, we found that for Whites displaced to a gentrifying neighborhood after Katrina, BMI was significantly lower than for Whites living in consistently low-income neighborhoods. For self-rated health, all adjusted, unadjusted and subgroup analysis showed non-significant effects with estimates close to zero. Our analysis of psychological stress similarly showed no effect, other than for participants living in majority Black neighborhoods, where gentrification caused significantly higher psychological distress than in neighborhoods with other racial compositions. Given that we conducted a large number of tests for effect modification (Wang et al., 2007), the significant subgroup effects should be interpreted cautiously.

5.1. Explanation and interpretation of findings

There are several possible explanations for our findings of no significant main effects of gentrification on health. First, we may have been underpowered to detect a real effect, as we had a relatively small sample size. However, our effect sizes, especially for self-rated health, were close to zero across models, and previous research using this dataset had sufficient power to show statistically significant associations between county sprawl and BMI (Arcaya et al., 2014b).

Second, gentrification, as measured by change in the census tract to county median household income between 2000 and 2006, may not cause self-reported BMI, psychological wellbeing, or self-rated health to change. Gentrification may also positively and negatively affect health, and the bi-directional effects may cancel out any net-effect. Though the effects were only significant at the point five-level in two of our subgroup analysis, the direction of the effect differed for subgroups across outcomes, which is suggestive that there may have been heterogeneous treatment effects present, and worth future examination. Given that we performed twenty-four total analyses, we would expect one-to-two significant analysis due to chance. It is also possible that these findings are unique to BMI, psychological stress, and self-rated health. Though we tested measures of general health, mental health, and physical health,

there may be unidirectional impacts that our measures of health failed to capture.

The context of Hurricane Katrina may be unique and limit the generalizability of our study findings. The overall trauma and disruption of Hurricane Katrina, and forced displacement after the storm, may have overwhelmed any effects of neighborhood socioeconomic and cultural transformation and may have contributed to our null findings. 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 (Henderson et al., 2015). In our study population, only 27% of respondents indicated that from 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 2006 neighborhoods. Long-term neighborhood residents may be most susceptible to impacts of gentrification, as they are more deeply embedded in their community. Our study participants were largely new to the communities they were displaced to, and many were only exposed to a gentrifying neighborhood for a limited time period. Though much of the literature on gentrification has not differentiated between impacts for long-and short-term residents, Schnake-Mahl et al. suggests that length of residence may be an important modifying factor in the effects of gentrification on health (Schnake-Mahl et al., 2019). The high levels of mobility and limited exposure time may have mitigated any neighborhood effects, as research suggests that neighborhood exposures may need to accumulate over time to impact health (Diez Roux, 2007).

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.

5.2. Comparison to other literature

Other studies on gentrification and health have found disparate associations between gentrification and health, including no significant main effects but increased odds of adverse outcomes for a subgroup or multiple subgroups (Izenberg et al., 2018). A systematic review of quantitative studies on gentrification, neighborhood change, and health found that estimated relationships varied by the outcome, period and subgroup studied, and operationalization of gentrification (Schnake--Mahl et al., 2019). Generally, quantitative studies have detected smaller consequences of gentrification than qualitative studies (Brown-Saracino, 2013). The significant findings in other quantitative studies may 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 (Lee, 2010). Using an earthquake as an instrumental variable, Lee, 2010 found no significant effect of gentrification on crime in low-income tracts but found that in the short-term gentrification increased the number of assaults in moderate-income neighborhoods (Lee, 2010). Given the contentious debates about the causal relationship between neighborhoods and health (Ellen et al., 2001; Arcaya et al., 2016; Diez Roux and Neighborhoods, 2010), and susceptibility of estimates to confounding by neighborhood selection, quasi-experimental designs represent a major methodological improvement to previous work.

5.3. Natural disaster and recovery inequities

Tragically, natural disasters such as Katrina are increasing in frequency (Smith and Katz, 2013), and have in some cases also catalyzed neighborhood change, pushing out some residents and attracting others (Lee, 2010, 2017). Although gentrification began in New Orleans well before the storm, the rebuilding of the city exacerbated existing trends in gentrification and spatial inequity (Seicshnaydre and Collins, 2018; Housing Authority of New Orleans, 2016). Areas with more severe physical property damage were more likely to change (Landry et al., 2007; Kamel, 2012). And, because of preexisting social and economic inequalities, low-income areas are often disproportionately impacted by natural disasters (Cutter et al., 2008), and experience worse baseline health indicators (Davis et al., 2010). Low-income groups are also slowest to return after catastrophes, and often have the most difficulty rebuilding because of low rates of investment in hazard mitigation such as natural hazard insurance (Peacock and Girard, 1997), as well as limited access to recovery resources and health care access (Davis et al., 2010; Quarantelli, 2003). Studies after Katrina showed that low-income Black households were more likely to leave after the storm (Frey and Singer, 2006), and renters and Black families were less likely to return to their pre-Katrina homes, in comparison to higher income and White families (Elliott and Pais, 2006; Mueller et al., 2011).

Exogenous shocks such as storms can exacerbate existing spatial inequality. Natural hazards differentially impact neighborhood change processes according to prior neighborhood characteristics (Pais and Elliott, 2008). While building resilience to future storms is integral to rebuilding, respecting residents' right to remain in their prior neighborhoods should also be prioritized (Henderson et al., 2015; NOLA, 2015; Office of Community Development, 2017), 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, 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.

5.4. Limitations

Our natural experiment design represents a novel method of exploring the relationship between gentrification and health because it allows us to reduce the threat of bias due to neighborhood selection. However, the study does have several limitations. 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 time-varying confounders may remain despite the robust study design. To remove potential selection effects, we measure assignment to neighborhoods immediately post-Katrina, in 2006. In 2006, only 46% of the study population was living in the New Orleans area, so much of the gentrification, we measure occurred outside of New Orleans. Since 2010 however, the city has undergone substantial gentrification (Seicshnaydre and Collins, 2018; Housing Authority of New Orleans, 2016). Preliminary review of qualitative data from the 4th wave (2016–2018) of the RISK project suggest that gentrification is a major concern for participants (Johnson, 2019). Analysis of more recent gentrification and the effects on health of RISK participants living back in New Orleans may show results differing from ours, though such analysis will be susceptible to selection effects. Different impacts may emerge with a reanalysis of the 4th wave of the project because of the more-extended lag-time after exposure to gentrifying neighborhoods.

Additionally, our measure of gentrification may be imprecise and may not be able to distinguish gentrification from other forms of neighborhood transition. Our measure relies on census data that 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 correlated well with other indicators of gentrification (Bostic and Martin, 2003; Ding et al., 2015), and 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. We tested several alternative specifications of our gentrification measure, and results were not sensitive to changes in the measure. Given the numerous existing measures of gentrification, it is possible that alternative specifications of our exposure, such as those including context-specific measures, may have produced different associations between gentrification and health.

Our measure of gentrification may also understate upgrading in neighborhoods where the whole metropolitan area was growing economically. However, given the period of study, during and immediately following the peak of the financial crash, it is unlikely that metro areas grew economically overall.

Our outcomes are self-reported, which can 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. 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. Finally, participants were largely new to the neighborhoods they were displaced to, and length of residence in a gentrifying neighborhood likely moderates effects on health. Broadly speaking, gentrification could impact health in a variety of ways. But, being unwillingly displaced from one's long-term residence by gentrification is likely one key pathway that our study cannot evaluate since in this case all participants were displaced and we measure what happens after displacement. Our study uses a rigorous study design to show that living in a gentrifying neighborhood for a short time does not appear to harm health. But, we cannot directly comment on what happens to long-term residents who are displaced by gentrification.

6. Conclusion

This article is, to our knowledge, among the first to use a natural experiment to examine the relationship between a neighborhood exposure and individual health (Arcaya et al., 2014b; Deryugina and Molitor, 2018). The quasi-experimental design allows us to examine the associations between neighborhood change and health, net of selection into neighborhoods, a major concern in the observational literature on gentrification and health. Among participants exposed to a natural disaster, we find no detectable effects of displacement to gentrifying neighborhoods. While gentrification may well have important social and economic effects in some settings, we do not find quantitative evidence for health impacts of displacement to gentrifying neighborhoods in this population of survivors of Hurricane Katrina.

Funding

This work was supported by the Lee Kum Sheung Center for Health and Happiness Dissertation Award; and the National Institutes of Health Grants R01HD046162, RO1HD057599 and P01 HD082032-02.

Declaration of competing interest

None.

References

Anderson, M.B., Sternberg, C., 2013. "Non-White" gentrification in chicago's bronzeville and pilsen: racial economy and the intraurban contingency of urban redevelopment. Urban Aff. Rev. 49 (3), 435–467.

Arcaya, M.C., Subramanian, S., Rhodes, J.E., Waters, M.C., 2014a. Role of health in predicting moves to poor neighborhoods among Hurricane Katrina survivors. Proc. Natl. Acad. Sci. 111 (46), 16246–16253.

Arcaya, M., James, P., Rhodes, J.E., Waters, M.C., Subramanian, S., 2014b. Urban sprawl and body mass index among displaced Hurricane Katrina survivors. Prev. Med. 65, 40–46.

Arcaya, M.C., Tucker-Seeley, R.D., Kim, R., Schnake-Mahl, A., So, M., Subramanian, S., 2016. Research on neighborhood effects on health in the United States: a systematic review of study characteristics. Soc. Sci. Med. 168, 16–29.

Arcaya, M.C., Schnake-Mahl, A., Binet, A., et al., 2018. Community change and resident needs: designing a participatory action research study in metropolitan boston. Health Place 52, 221–230.

Bostic, R.W., Martin, R.W., 2003. Black home-owners as a gentrifying force? Neighbourhood dynamics in the context of minority home-ownership. Urban Stud. 40 (12), 2427–2449.

Britton, M.L., Shin, H., 1982. Metropolitan residential segregation and very preterm birth among African American and Mexican-origin women. Soc. Sci. Med. 98 (2013), 37–45.

Brown-Saracino, J., 2013. The Gentrification Debates: a Reader. Routledge.

Chaix, B., Merlo, J., Evans, D., Leal, C., Havard, S., 2009. Neighbourhoods in eco-epidemiologic research: delimiting personal exposure areas. A response to Riva, Gauvin, Apparicio and Brodeur. Soc. Sci. Med. 69 (9), 1306–1310.

Chan, C.S., Lowe, S.R., Weber, E., Rhodes, J.E., 2015. The contribution of pre-and postdisaster social support to short-and long-term mental health after Hurricanes Katrina: a longitudinal study of low-income survivors. Soc. Sci. Med. 138, 38–43.

Charles, C.Z., 2003. The dynamics of racial residential segregation. Annu. Rev. Sociol. 29 (1), 167–207.

Charles, S.L., 2013. Understanding the determinants of single-family residential redevelopment in the inner-ring suburbs of Chicago. Urban Stud. 50 (8), 1505–1522.

Contoyannis, P., Jones, A.M., Rice, N., 2004. The dynamics of health in the British household panel survey. J. Appl. Econom. 19 (4), 473–503.

Corral, I., Landrine, H., Hall, M.B., Bess, J.J., Mills, K.R., Efird, J.T., 2015. Residential segregation and overweight/obesity among African-American adults: a critical review. Front. Public Health 3 (169).

Cutrona, C.E., Russell, D.W., 1987. The provisions of social relationships and adaptation to stress. Adv. Pers. Relat. 1 (1), 37–67.

Cutter, S.L., Barnes, L., Berry, M., et al., 2008. A place-based model for understanding community resilience to natural disasters. Glob. Environ. Chang. 18 (4), 598–606.

Davis, J.R., Wilson, S., Brock-Martin, A., Glover, S., Svendsen, E.R., 2010. The impact of disasters on populations with health and health care disparities. Disaster Med. Public Health Prep. 4 (1), 30–38.

Deryugina, T., Molitor, D., 2018. Does when You Die Depend on where You Live? Evidence from Hurricane Katrina. NBER Working Paper. No. 24822.

Desmond, M., Kimbro, R.T., 2015. Eviction's fallout: housing, hardship, and health. Soc. Forces 94 (1), 295–324.

Diez Roux, A.V., 2001. Investigating neighborhood and area effects on health. Am. J. Public Health 91 (11), 1783–1789.

Diez Roux, A.V., 2007. Neighborhoods and health: where are we and were do we go from here? Rev. Epidemiol. Sante Publique 55 (1), 13–21.

Diez Roux, A.V., Mair, C., 2010. Neighborhoods and health. Ann. N. Y. Acad. Sci. 1186 (1), 125–145.

Ding, L., Hwang, J., Divringi, E.E., 2015. Gentrification and residential mobility in Philadelphia. Reg. Sci. Urban Econ. 61 (1), 38–51.

Ellen, I.G., Glied, S., 2015. Housing, neighborhoods, and children's health. Future Child. 25 (1), 135–153.

Ellen, I.G., O'Regan, K., 2008. Reversal of fortunes? Lower-income urban neighbourhoods in the US in the 1990s. Urban Stud. 45 (4), 845–869.

Ellen, I.G., O'Regan, K.M., 2011. How low income neighborhoods change: entry, exit, and enhancement. Reg. Sci. Urban Econ. 41 (2), 89–97.

Ellen, I.G., Mijanovich, T., Dillman, K.N., 2001. Neighborhood effects on health: exploring the links and assessing the evidence. J. Urban Aff. 23 (3-4), 391–408.

Elliott, J.R., Pais, J., 2006. Race, class, and Hurricane Katrina: social differences in human responses to disaster. Soc. Sci. Res. 35 (2), 295–321.

Finch, B.K., Hummer, R.A., Reindl, M., Vega, W.A., 2002. Validity of self-rated health among Latino (a) s. Am. J. Epidemiol. 155 (8), 755–759.

Formoso, D., NW, R., SA, M., 2010. Gentrification and urban children's well-being: tipping the scales from problems to promise. Am. J. Community Psychol. 46 (3–4), 395–412.

Frey, W.H., Singer, A., 2006. Katrina and Rita Impacts on Gulf Coast Populations: First Census Findings. Brookings Institution, Metropolitan Policy Program Washington.

Fullilove, M.T., 1996. Psychiatric implications of displacement: contributions from the psychology of place. Am. J. Psychiatry 153, 12.

Furukawa, T.A., Kessler, R.C., Slade, T., Andrews, G., 2003. The performance of the K6 and K10 screening scales for psychological distress in the Australian National Survey of Mental Health and Well-Being. Psychol. Med. 33 (2), 357–362.

Fussell, E., 2012. Help from Family, Friends, and Strangers during Hurricane Katrina: Finding the Limits of Social Networks. Displaced: Life in the Katrina Diaspora, pp. 150–166.

Galea, S., Brewin, C.R., Gruber, M., et al., 2007. Exposure to hurricane-related stressors and mental illness after Hurricane Katrina. Arch. Gen. Psychiatr. 64 (12), 1427–1434.

Gibbons, J., Yang, T.-C., 2014. Self-rated health and residential segregation: how does race/ethnicity matter? J. Urban Health 91 (4), 648–660.

Gibbons, J., Barton, M., Barton, M.S., 2016. The association of minority self-rated health with black versus white gentrification. J. Urban Health 93 (6), 909–922.

Henderson, M., Davis, B., Climek, M., 2015. Views of Recovery Ten Years after Katrina and Rita. Louisiana State University Reilly Center for Media & Public Affairs, Baton Rouge.

Housing Authority of New Orleans, 2016. Assessment of Fair Housing Tool. New Orleans.

Huynh, M., Maroko, A.R., 2014. Gentrification and preterm birth in New York City, 2008-2010. J. Urban Health 91 (1), 211–220.

Hwang, J., Lin, J., 2016. What have we learned about the causes of recent gentrification? Cityscape 18 (3), 9–26. No. 16-20.
Hwang, J., Sampson, R.J., 2014. Divergent pathways of gentrification racial inequality and the social order of renewal in Chicago neighborhoods. Am. Sociol. Rev. 79 (4), 726–751.
Idler, E.L., Russell, L.B., Davis, D., 2000. Survival, functional limitations, and self-rated health in the NHANES I epidemiologic follow-up study, 1992. Am. J. Epidemiol. 152 (9), 874–883.
Ingram, D.D., SJ, F., 2012. NCHS Urban-Rural Classification Scheme for Counties. Vital Health Statistics 2 154, 1–65.
Izenberg, J.M., Mujahid, M.S., Yen, I.H., 2018. Health in changing neighborhoods: a study of the relationship between gentrification and self-rated health in the state of California. Health Place 52, 188–195.
James, P., Hart, J.E., Arcaya, M.C., Feskanich, D., Laden, F., Subramanian, S., 2015. Neighborhood self-selection: the role of pre-move health factors on the built and socioeconomic environment. Int. J. Environ. Res. Public Health 12 (10), 12489–12504.
Johnson, S., 2019. Email to the Author.
Jones, A., 2013. Segregation and cardiovascular illness: the role of individual and metropolitan socioeconomic status. Health Place 22, 56–67.
Jylhä, M., 2009. What is self-rated health and why does it predict mortality? Towards a unified conceptual model. Soc. Sci. Med. 69 (3), 307–316.
Kamel, N., 2012. Social marginalisation, federal assistance and repopulation patterns in the New Orleans metropolitan area following Hurricane Katrina. Urban Stud. 49 (14), 3211–3231.
Kawachi, I., Berkman, L., Glymour, M., 2014. Social cohesion, social capital, and health. In: Kawachi, I., Berkman, L. (Eds.), Social Epidemiology. New York Oxford University Press, pp. 290–319.
Kessler, R.C., Barker, P.R., Colpe, L.J., et al., 2003. Screening for serious mental illness in the general population. Arch. Gen. Psychiatr. 60 (2), 184–189.
Krieger, N., Chen, J.T., Waterman, P.D., Soobader, M.-J., Subramanian, S., Carson, R., 2003. Choosing area based socioeconomic measures to monitor social inequalities in low birth weight and childhood lead poisoning: the Public Health Disparities Geocoding Project (US). J. Epidemiol. Community Health 57 (3), 186–199.
Landis, J.D., 2016. Tracking and explaining neighborhood socioeconomic change in US metropolitan areas between 1990 and 2010. Hous. Policy Debate 26 (1), 2–52.
Landry, C.E., Bin, O., Hindsley, P., Whitehead, J.C., Wilson, K., 2007. Going home: evacuation-migration decisions of hurricane Katrina survivors. South. Econ. J. 326–343.
Lee, Y.Y., 2010. Gentrification and crime: identification using the 1994 northridge earthquake in los angeles. J. Urban Aff. 32 (5), 549–577.
Lee, D., 2017. Neighborhood change induced by natural hazards. J. Plan. Lit. 32 (3), 240–252.
Lee, S., Lin, J., 2018. Natural amenities, neighborhood dynamics, and persistence in the spatial distribution of income. The Review of Economic Studies 85 (1), 663–694. Paper No 13-48.
Lees, L., Slater, T., Wyly, E., 2013. Gentrification. Routledge.
Little, R.J., 1988. A test of missing completely at random for multivariate data with missing values. J. Am. Stat. Assoc. 83 (404), 1198–1202.
Logan, J.R., Xu, Z., Stults, B.J., 2014. Interpolating US decennial census tract data from as early as 1970 to 2010: a longitudinal tract database. Prof. Geogr. 66 (3), 412–420.
Lowe, S.R., Rhodes, J.E., Waters, M.C., 2015. Understanding resilience and other trajectories of psychological distress: a mixed-methods study of low-income mothers who survived Hurricane Katrina. Curr. Psychol. 34 (3), 537–550.
Ludwig, J., Sanbonmatsu, L., Gennetian, L., et al., 2011. Neighborhoods, obesity, and diabetes—a randomized social experiment. N. Engl. J. Med. 365 (16), 1509–1519.
Macintyre, S., Ellaway, A., Cummins, S., 2002. Place effects on health: how can we conceptualise, operationalise and measure them? Soc. Sci. Med. 55 (1), 125–139.
Markley, S., 2018. Suburban gentrification? Examining the geographies of New Urbanism in Atlanta's inner suburbs. Urban Geogr. 39 (4), 606–630.
McKinnish, T., Walsh, R., White, T.K., 2010. Who gentrifies low-income neighborhoods? J. Urban Econ. 67 (2), 180–193.
Meltzer, R., 2016. Gentrification and small business: threat or opportunity? Cityscape 18 (3), 57–86.
Mewton, L., Kessler, R.C., Slade, T., et al., 2016. The psychometric properties of the Kessler Psychological Distress Scale (K6) in a general population sample of adolescents. Psychol. Assess. 28 (10), 1232.
Miller, R.B., Hollist, C.S., 2007. Attrition bias. In: Salkind, N.J. (Ed.), Encyclopedia of Measurement and Statistics.
Mitchell, C.M., Beals, J., 2011. The utility of the kessler screening scale for psychological distress (K6) in two American Indian communities. Psychol. Assess. 23 (3), 752.
Mueller, E.J., Bell, H., Chang, B.B., Henneberger, J., 2011. Looking for home after Katrina: postdisaster housing policy and low-income survivors. J. Plan. Educ. Res. 31 (3), 291–307.
Mujahid, M.S., Roux, A.V.D., Shen, M., et al., 2008. Relation between neighborhood environments and obesity in the multi-ethnic study of atherosclerosis. Am. J. Epidemiol. 167 (11), 1349–1357.
NOLA, H., 2015. 10 Year Strategy and Implementation Plan for a More Equitable New Orleans. New Orleans Greater New Orleans Housing Alliance (GNOHA).
Office of Community Development, 2017. Housing For a Resilient New Orleans. City of New Orleans.
Pais, J.F., Elliott, J.R., 2008. Places as recovery machines: vulnerability and neighborhood change after major hurricanes. Soc. Forces 86 (4), 1415–1453.
Papachristos, A.V., Smith, C.M., Scherer, M.L., Fugiero, M.A., 2011. More coffee, less crime? The relationship between gentrification and neighborhood crime rates in chicago, 1991 to 2005. City Commun. 10 (3), 215–240.
Peacock, W.G., Girard, C., 1997. Ethnic and Racial Inequalities in Hurricane Damage and Insurance Settlements. Hurricane Andrew: Ethnicity, Gender and the Sociology of Disasters, pp. 171–190.
Prus, S.G., 2011. Comparing social determinants of self-rated health across the United States and Canada. Soc. Sci. Med. 73 (1), 50–59.
Quarantelli, E.L., 2003. Urban Vulnerability to Disasters in Developing Societies: the Need for New Strategies and for Better Applications of Valid Planning and Managing Principles. University of Delaware.
Robert, S.A., 1999. Socioeconomic position and health: the independent contribution of community socioeconomic context 1. Annu. Rev. Sociol. 25 (1), 489–516.
Robert, S.A., Reither, E.N., 2004. A multilevel analysis of race, community disadvantage, and body mass index among adults in the US. Soc. Sci. Med. 59 (12), 2421–2434.
Rosenthal, S.S., 2008. Old homes, externalities, and poor neighborhoods. A model of urban decline and renewal. J. Urban Econ. 63 (3), 816–840.
Ruel, E., Reither, E.N., Robert, S.A., Lantz, P.M., 2010. Neighborhood effects on BMI trends: examining BMI trajectories for Black and White women. Health Place 16 (2), 191–198.
Schnake-Mahl, A., Jahn, J., Subramania, S.V., Gentrification, A.M., 2019. Neighborhood Change and Population Health: A Systematic Review. J Urban Health in press.
Schnittker, J., Bacak, V., 2014. The increasing predictive validity of self-rated health. PLoS One 9 (1), e84933.
Seicshnaydre, S., Collins, R.A., 2018. Rigging the Real Estate Market: Segregation, Inequality, and Disaster Risk. The Data Center.
Slater, T., 2006. The eviction of critical perspectives from gentrification research. Int. J. Urban Reg. Res. 30 (4), 737–757.
Smith, N., 1998. Gentrification. In: Vliet, W.V. (Ed.), The Encyclopedia of Housing, pp. 198–199.
Smith, A.B., Katz, R.W., 2013. US billion-dollar weather and climate disasters: data sources, trends, accuracy and biases. Nat. Hazards 67 (2), 387–410.
Stata Statistical Software, 2017. *Release 15* [computer Program]. Texas, USA.
Subramanian, S.V., Chen, J.T., Rehkopf, D.H., Waterman, P.D., Krieger, N., 2005. Racial disparities in context: a multilevel analysis of neighborhood variations in poverty and excess mortality among black populations in Massachusetts. Am. J. Public Health 95 (2), 260–265.
Tizon, T., Smith, D., December 12, 2005. Evacuees of Hurricane Katrina resettle along a racial divide. Los Angel. Times, 2005.
Venis Wilder, A.-L.M., Makoba, E., Arniella, G., 2017. The health impact of gentrification. J. Gen. Emerg. Med. 4, 1981–1991.
Vos, A.A., Posthumus, A.G., Bonsel, G.J., Steegers, E.A., Denktaş, S., 2014. Deprived neighborhoods and adverse perinatal outcome: a systematic review and meta-analysis. Acta Obstet. Gynecol. Scand. 93 (8), 727–740.
Wang, R., Lagakos, S.W., Ware, J.H., Hunter, D.J., Drazen, J.M., 2007. Statistics in medicine—reporting of subgroup analyses in clinical trials. N. Engl. J. Med. 357 (21), 2189–2194.
Williams KN. Transforming Communities and Crime?: an Examination of Gentrification and Crime in (St. Louis City).