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## Displacement and Mortality After a Disaster: Time-Series Analysis of Deaths of Puerto Ricans in the United States Post-Hurricane Maria

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3 1 **Displacement and Mortality After a Disaster:**  
4 2 **Time-Series Analysis of Deaths of Puerto Ricans in the United States Post-Hurricane Maria**  
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9 6 Mario Marazzi, PhD<sup>1</sup>, Boriana Miloucheva, M.A<sup>2</sup>, and Gustavo Bobonis, Ph.D<sup>3</sup>

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3 41 **Displacement and Mortality After a Disaster:**  
4 42 **Time-Series Analysis of Deaths of Puerto Ricans in the United States Post-Hurricane Maria**  
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6  
7 44 ***Abstract***

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9 45 *Objectives:* To determine death occurrences of Puerto Ricans on the mainland U.S. following the  
10 46 arrival of Hurricane Maria in Puerto Rico in September 2017.

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12 47 *Design:* Cross-sectional study

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14 48 *Participants:* Persons of Puerto Rican origin on the mainland United States

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16 49 *Exposures:* Hurricane Maria

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18 50 *Main Outcome:* We use an interrupted time-series design to analyze all-cause mortality of Puerto  
19 51 Ricans in the U.S. following the Hurricane. Hispanic Origin data from the National Vital Statistics  
20 52 System and from the Public Use Microdata Sample of the American Community Survey are used  
21 53 to estimate monthly origin-specific mortality rates for the period 2012 to 2018. We estimated log-  
22 54 linear regressions of monthly deaths of persons of Puerto Rican origin by age group, gender, and  
23 55 educational attainment.

24  
25 56 *Results:* We found an increase in mortality for persons of Puerto Rican origin during the 6-month  
26 57 period following the Hurricane (October 2017 through March 2018), suggesting that deaths among  
27 58 these persons were 3.7% (95% CI: 0.025-0.049) higher than would have otherwise been expected.  
28 59 In absolute terms, we estimated 514 excess deaths (95% CI 346 – 681) of persons of Puerto Rican  
29 60 origin that occurred on the mainland U.S., concentrated in those aged 65 years or older.

30  
31 61 *Conclusions:* Our findings suggest an undercounting of previous deaths as a result of the hurricane  
32 62 due to the systematic effects on the displaced and resident population in the mainland U.S.  
33 63 Displaced populations are frequently overlooked in disaster relief and subsequent research.  
34 64 Ignoring these populations provides an incomplete understanding of the damages and loss of life.

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3 774  
5 786 79 *Article Summary*7  
8 80 *Strengths and limitations*

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10 81 • One of the first studies to examine excess mortality of persons displaced by natural  
11 82 disasters.
- 12 83 • Leverage comparison group mortality outcomes to control for seasonality and period-  
13 84 specific effects, minimizing potential confounding.
- 14 85 • Generate independent estimates of population displacement from the territory to the  
15 86 mainland U.S following Hurricane Maria
- 16 87 • As the mortality outcomes are aggregated at the Hispanic group and gender-age group  
17 88 stratum in each month, we are unable to precisely measure cause-specific mortality.

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## 93 I. Introduction

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95 Extreme weather events such as hurricanes are growing in frequency and magnitude and are  
96 expected to affect a growing population due to migration patterns, ecosystem alteration, and  
97 climate.<sup>1,2</sup> The consequences for human lives and the economic costs associated with these  
98 disasters are high.<sup>3,4</sup> While much research documents the direct impacts of natural disasters on the  
99 mortality, morbidity, and socioeconomic consequences of populations in affected areas,  
100 substantially less attention has been paid to the consequences for populations displaced as a result  
101 of these events.<sup>3,5,6</sup>

102  
103 While all victims of natural disasters face common challenges, displaced populations undergo  
104 distinct experiences that are specific to their relocation—such as additional psychological stressors  
105 and disruption in access to healthcare services as well as changes in their living conditions and  
106 social networks.<sup>1</sup> These circumstances can either compound or mitigate the effects of disasters for  
107 these populations. Consistent with the heterogeneity in the populations' experiences, a growing  
108 body of research finds mixed evidence regarding the incidence and extent of higher mortality risk  
109 among displaced populations.<sup>2</sup>

110  
111 However, measuring the mortality consequences of disasters among these populations is inherently  
112 challenging due to the displacement that can take place before, during or in the aftermath of an  
113 event.<sup>3</sup> Few studies of displaced populations have analyzed representative sample data before and  
114 after exposure to a disaster relative to comparable populations to be able to credibly measure the  
115 effects of these events.<sup>4</sup> In spite of these methodological limitations, this literature has shaped our  
116 understanding of mortality patterns among displaced populations. If conclusions about these forms

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<sup>1</sup> See Uscher-Pines and Frankenberg, Laurito, and Thomas for systematic reviews of the literatures on the health effects of relocation following disaster and of the demographic consequences of disasters more generally.<sup>18,19</sup>

<sup>2</sup> In an early systematic review of the literature, Uscher-Pines documents no short nor long-term consequences on mortality for displaced populations following post-disaster relocation.<sup>19</sup> Subsequent studies find higher mortality risks for specific displaced subpopulations such as among relocated institutionalized elderly; see Willoughby et al. for a systematic review.<sup>20</sup>

<sup>3</sup> Most data on disasters are obtained from those who remain relatively near the site of the disaster or who have relocated to obvious camps and refugee settlements. The mortality of the rest of the displaced population may be missed if proper attention is not taken in the design of data collection efforts. Furthermore, displacement makes it difficult to know how completely those interviewed represent the underlying population exposed to the event, nor is it possible to benchmark respondents' experiences during and after an event against their circumstances before the event, or against populations that were not exposed to the event but are otherwise similar.<sup>6,21</sup>

<sup>4</sup> Specifically, studies of populations after large-scale disasters typically describe the experiences of particular groups of individuals—such as those displaced to specialized refugee locations—providing little information about individuals who settled elsewhere, although there are exceptions.<sup>6,17,18,21–26</sup>

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3 117 of vulnerability do not transcend specific groups and cannot be replicated more generally, their  
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5 118 informativeness in planning for or responding to the needs of at-risk populations—monitoring,  
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7 119 assessment, programming of interventions and the targeting of social safety nets—is compromised.  
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10 121 In this article, we contribute to research on the mortality consequences of extreme environmental  
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12 122 hazards among displaced populations in host communities.<sup>5</sup> We study the excess mortality  
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14 123 experienced by Puerto Ricans in the mainland U.S. following the devastation caused in Puerto  
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16 124 Rico by Hurricanes Irma and Maria in September 2017. We combine administrative death records  
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18 125 data from the U.S. National Vital Statistics System together with population estimates using  
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20 126 repeated cross-sections of the Public Use Microdata Sample of the American Community Survey  
21  
22 127 to estimate monthly immigrant-origin group-specific mortality rates by age, gender, and  
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24 128 educational attainment for the period 2012 to 2018 in the mainland U.S. Using these data, which  
25  
26 129 is representative of the at-risk population, we conduct analyses that measure outcomes consistently  
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28 130 for individuals from the group affected by the disaster relative to those of comparable populations.  
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31 132 We use an interrupted time-series differences-in-differences design to examine patterns of all-  
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33 133 cause mortality of Puerto Ricans in the United States during the months following the Hurricane,  
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35 134 using mortality trends for Cuban and Mexican populations in the mainland U.S.—whose countries  
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37 135 of origin or ancestry were not affected by extreme hurricanes that year (or limited population  
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39 136 displacement to the U.S. as a result of these events) and who had historically similar mortality  
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41 137 trends preceding the event—as a comparison group. The design we employ robustly accounts for  
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43 138 different mortality trends by age group and gender to identify the potentially greater mortality risk  
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45 139 among the Puerto Rican population in the mainland.  
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48 141 Our study documents a systematic increase in mortality among Puerto Ricans on the mainland in  
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50 142 the six-month period in the aftermath of the Hurricanes that is concentrated among old-age  
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52 143 populations. Analyses of these data also provide a rich description of heterogeneity of the event's  
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54 144 impacts to yield generalizable knowledge.  
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55 <sup>5</sup> We conceptualize post-disaster mobility as a coping strategy that occurs along a spectrum from forced displacement to largely  
56 voluntary migration.<sup>6,27–29</sup>  
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3 146 From a substantive point of view, we add to the literature on the effects of Hurricane Maria on  
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5 147 Puerto Rico. The consensus from existing research documenting excess mortality in the aftermath  
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7 148 of the Hurricanes—based on death occurrences that happened physically in the archipelago of  
8  
9 149 Puerto Rico—is that well over one thousand people died in Puerto Rico and likely more than three  
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11 150 thousand lost their lives (see Supplementary Materials Table A1).<sup>7–11</sup> However, to date, no  
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13 151 systematic attempt had been made to consider deaths that may have occurred on the mainland  
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15 152 United States as a result of this natural disaster.

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### 154 **I. Data and Descriptive Statistics**

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156 We use publicly available microdata from the National Vital Statistics System of the National  
157 Center for Health Statistics to identify deaths of persons of Puerto Rican origin on the mainland  
158 United States between 2012 and 2018. The data also allows us to identify deaths of persons of  
159 other Hispanic origins, which we use as a comparison group. It also includes the month of  
160 occurrence, as well as several socio-economic variables for each death, including the person's age,  
161 gender, and educational attainment.

162

163 We use the Public Use Microdata Sample of the American Community Survey (ACS) of the U.S.  
164 Census Bureau to estimate the annual population of each Hispanic origin, for each age group,  
165 gender, and educational attainment between 2012 and 2018. Following Santos Burgoa et al.  
166 (2018), age was categorized in three groups: 0-39 years, 40-64 years, and 65 years or older. For  
167 age groups 40-64 years and 65 years and older, we also stratified the sample in three groups based  
168 on individuals' educational attainment: persons who did not complete high school, those with only  
169 a high school degree, and those with some higher education or more.

170

171 We employ a standard temporal disaggregation method for time series data based on dynamic  
172 models to generate stratum-specific population measures for each month.<sup>12,13</sup> The technique  
173 exploits the time-series relationship of the available low-frequency data using a regression model  
174 with autocorrelated errors generated by a first-order autoregressive process. The reference period  
175 of the ACS is the 12-month calendar year. As a result, we also restrict the 12-month average

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3 176 population estimate to equal the annual ACS-based population estimate; see Supplementary  
4 177 Materials for details.

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8 179 Because these data are publicly available and deidentified, this study is considered to be research  
9 180 not involving human subjects as defined by U.S. regulation (45 CFR 46.102[d]).

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11 181  
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13 182 We compare mortality outcomes pre and post September 2017 among the Puerto Rican population  
14 183 in the mainland U.S. relative to other Hispanic groups in the country. In Panel A of Figure 1 we  
15 184 examine trends in the overall mortality rate of Puerto Ricans in the mainland U.S. (blue solid line)  
16 185 during January 2012-December 2018 and that of Cubans and Mexicans (red dashed line)  
17 186 throughout the same period. Between January of 2012 and August 2017, the mortality rate among  
18 187 individuals of Puerto Rican ancestry averaged 38.86 per 100,000. In contrast, the mortality rate  
19 188 among Cubans and Mexicans throughout this period was 31.48 per 100,000. In spite of this  
20 189 difference in the level of mortality, the two groups experienced very similar seasonal patterns and  
21 190 trends in their mortality in the period up to September 2017, when Puerto Rico was severely  
22 191 affected by Hurricanes Irma and Maria (Figure 1, panel A).

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24 192  
25 193 Following these events, we observe a modest trend break in the mortality rate of Puerto Ricans  
26 194 relative to that of Cubans and Mexicans, in the 0.08-4.03 deaths per 100,000 range (Figure 1,  
27 195 panel B). The figure helps validate the research design (see Section III below). Moreover, it reveals  
28 196 the mortality rate gap to be most pronounced during the October 2017 through March 2018; we  
29 197 use this post-Hurricane six-month event window to capture estimates of excess mortality for the  
30 198 Puerto Rican population in the mainland U.S.

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## 35 203 **II. Patient and Public Involvement**

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37 205 No patients involved.

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### 207 III. Methods

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209 Our empirical strategy consists of a difference-in-differences design. We compare differences in  
 210 the mortality rates of Puerto Ricans before and after September 2017 relative to that of Cubans  
 211 and Mexicans, comparable Hispanic groups in the U.S., during the January 2012-December 2018  
 212 time period. In doing so, we effectively use the mortality outcomes of the comparison groups to  
 213 control for seasonality and period-specific effects.<sup>6</sup> We make these comparisons by gender and  
 214 age group, estimating a system of six (6) linear models of the form:

215

$$216 \ln(d_{sgmt}) = \theta_s(\text{Maria}_{mt} \times \text{PR}_{sg}) + \beta_s \ln(\text{Pop}_{sgmt}) + \alpha_{sg} + \gamma_{mt} + \varepsilon_{sgmt}, \quad (1)$$

217

218 where  $d_{sgmt}$  is the number of deaths of individuals from gender-age group stratum  $s$  and Hispanic  
 219 group  $g$  in month  $m$  and year  $t$ ;  $\text{Maria}_{mt}$  is an indicator variable for the 6-month period from October  
 220 2017 to the March 2018;  $\text{PR}_{sg}$  is an indicator variable for Puerto Rican origin;  $\text{Pop}_{sgmt}$  is the  
 221 population level estimate for each Hispanic group  $g$  over time;  $\alpha_{sg}$  are Hispanic group fixed effects;  
 222  $\gamma_{mt}$  are month-by-year fixed effects; and  $\varepsilon_{sgmt}$  is the error term. This model richly captures  
 223 seasonality as well as other time trends for each gender-by-age stratum, and accounts for  
 224 differences in the mortality rate levels between Puerto Ricans and other Hispanic groups. We  
 225 estimate the models as a system of equations allowing for autocorrelation of the error terms by  
 226 clustering standard errors at the Hispanic group level.<sup>14-16</sup> This procedure also allows us to account  
 227 for the correlation of mortality rates across age groups and gender within each Hispanic group as  
 228 well as the autocorrelation of mortality for each group, and to generate estimates of aggregate  
 229 excess mortality for the population based on the stratum-specific models.

230

231 We also report a series of estimates from an event study to document the month-specific effects of  
 232 the Maria shock. Specifically, we estimate equation (2) to explore this:

233

$$234 \ln(d_{sgmt}) = \theta_{st} \cdot \mathbf{I}\{g = \text{PR}_g\} \cdot \mathbf{I}\{t = 1, 2, \dots, 6\} + \beta_s \ln(\text{Pop}_{sgmt}) + \alpha_{sg} + \gamma_{mt} + \varepsilon_{sgmt}, \quad (2)$$

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<sup>6</sup> The results are robust to restricting the sample to start in later years (i.e., 2013, 2014), but with somewhat lower levels of precision.

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3 236 where  $I\{g = PR_g\} \cdot I\{t = 1, 2, \dots, 6\}$  is a vector capturing the interaction of the PR indicator with an  
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5 237 indicator variable for each month from October 2017 to March 2018, with September 2017 – the  
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7 238 month of the event – as the base period. All other variables are as defined above in equation (1).  
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9 239 The vector  $\theta_{st}$  captures the period-specific effects for each month during the 6-month window  
10 240 described earlier.

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12 241  
13 242 Our estimation procedure uses the observed age-group-by-gender specific deaths that occurred  
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15 243 over the period of September 2017 until March 2018 as well as our estimated coefficients of the  
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17 244 differential change in mortality rates of Puerto Ricans in the mainland U.S. ( $\theta_s, \theta_{st}$ ), to construct  
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19 245 estimates of excess mortality for each age-group-sex combination and their corresponding 95  
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21 246 percent confidence interval. We follow an analogous procedure to generate estimates of excess  
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23 247 mortality for the population in overall terms. See Supplementary Materials for details of the  
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25 248 estimation and aggregation procedures.

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27 250 An important consideration in this analysis is our need to estimate the degree of population  
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29 251 displacement of the residents of Puerto Rico to the mainland U.S. following the hurricanes. We do  
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31 252 so by measuring differential changes in population levels for the Puerto Rican population in the  
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33 253 mainland U.S. relative to trends for the comparison groups throughout the period following the  
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35 254 Hurricanes. This methodology, described in more detail the Supplementary Materials, generates  
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37 255 estimates of population displacement, or the population in excess of what would have otherwise  
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39 256 been expected. This procedure allows us to both confirm independent estimates of population  
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41 257 movements from the territory to the mainland U.S. during this period and to give confidence to the  
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43 258 use of population estimates for the estimation of excess mortality rates.

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#### 45 260 **IV. Results**

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48 262 14,010 individuals of Puerto Rican background died in the mainland U.S. between October 2017  
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50 263 and March 2018 (Table 1); 7,505 (53.6%) were men and 6,505 (46.4%) were women (Table 2);  
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52 264 9,045 (64.6%) were adults aged 65 years or older (Table 3). In contrast, 10,866-12,832 deaths  
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54 265 occurred among this population in the six-month period between October and March in the 2012-  
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56 266 13 to 2016-17 years, the period of observation before the hurricane. We estimated that there were

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267 approximately 5·631 million individuals of Puerto Rican origin in the mainland U.S. in August  
268 2017, and by March 2018, this number was 5·783 million—an increase of approximately 152,000  
269 individuals, or a 2·7 percent population increase (Table 1).

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271 **Table 1: Excess Mortality of the Puerto Rican Population in the Mainland U.S., Overall and by Month (October 2017 – March 2018)**

	Observed deaths (1)	$\Delta$ Mortality Rate [95% CI] (2)	Population (100,000's) (3)	Expected Deaths (4)	Excess Deaths (5)	Ratio of Observed to Expected Mortality (6)
<b>Panel A: Month-Specific Estimates</b>						
October 2017	2,093	0.022 (-0.006, 0.051)	56.596	2,047	46 (-11.7, 104.1)	1.02 (0.99, 1.05)
November 2017	2,182	0.059 (0.041, 0.078)	56.767	2,056	126 (87.1, 164.7)	1.06 (1.04, 1.08)
December 2017	2,551	0.065 (0.048, 0.082)	56.974	2,391	160 (119.4, 200.7)	1.07 (1.05, 1.09)
January 2018	2,624	0.012 (-0.014, 0.039)	57.524	2,592	32 (-36.1, 100.5)	1.01 (0.99, 1.04)
February 2018	2,275	0.059 (0.035, 0.083)	57.708	2,145	130 (78.1, 182.4)	1.06 (1.03, 1.09)
March 2018	2,285	0.004 (-0.008, 0.016)	57.83	2,276	9 (-19.1, 36.8)	1 (0.99, 1.02)
<b>Panel B: Aggregate Estimates</b>						
October 2017 - March 2018	14,010	0.037 (0.025, 0.050)	57.233	13,496	514 (346.5, 681.0)	1.04 (1.03, 1.05)
October 2017 - December 2017	6,826	0.037 (0.024, 0.049)	56.779	6,581	245 (163.6, 326.9)	1.04 (1.02, 1.05)

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3 273 Our results span the six-month period following the passing of Hurricane Maria (October 2017 –  
4 274 March 2018). We find a statistically significant increase in the mortality rate for persons of Puerto  
5 275 Rican origin during this period of approximately 3·7 percent (95% CI 2·4 – 4·9 percent) higher  
6 276 than would have otherwise been expected (see Table 1). In absolute terms, this is equivalent to 514  
7 277 excess deaths (95% CI 346 – 681) of persons of Puerto Rican origin that occurred on the mainland  
8 278 United States.

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11  
12 280 The month-specific estimates of the excess mortality increase gradually throughout the fourth  
13 281 quarter and peak at 7·0 percent (95% CI 4·8 – 8·2 percent) in December 2017 and fluctuate in a  
14 282 downward trajectory during the first quarter of year 2018 (Table 1). These month-specific excess  
15 283 mortality rate estimates imply a pattern of excess death, starting just after the Hurricanes in October  
16 284 2017 with 46 excess deaths (95% CI -12 – 104), up to 160 (95% CI 119 – 201) in December 2017,  
17 285 and 9 (95% CI -19 – 37) in March 2018.

18  
19 286  
20 287 Table 2 reports estimates of excess mortality by age group and gender. Among the population aged  
21 288 65 years or older, mortality was higher than the expected pattern for this population throughout  
22 289 the October 2017-March 2018 period: 7·3 percent (95% CI 0·8 – 13·7 percent) for men and 6·4  
23 290 percent (95% CI 4·1 – 8·8 percent) for women. This is equivalent to 298 excess deaths for men  
24 291 (95% CI 162–366) and the same amount for women (95% CI 250–364).

25 292  
26 293 We find no robust evidence of differences in mortality from the expected pattern for the younger  
27 294 age population throughout this period. The empirical models suggest mortality decreased  
28 295 marginally by 0·5 percent (95% CI -0·5 – 1·6 percent) and 4·1 percent (95% CI 0·4 – 8·6 percent)  
29 296 among, respectively, men and women aged 40-64 years, and by 2·3 percent (95% CI 1·9 – 2·6  
30 297 percent) among men aged 0-39 years.

31 298  
32 299 The point estimates in Table 3 suggest that populations from all educational levels were affected,  
33 300 but excess deaths were more evident in certain groups. For example, we found 243 excess deaths  
34 301 (95% CI 154–332) occurred among old age women with less than high school, 175 excess deaths  
35 302 (95% CI 37–373) among old age men with a high school diploma, and 61(95% CI 39-83) and 102

303 **Table 2: Excess Mortality of the Puerto Rican Population in the Mainland U.S., by Age Group and Sex (October 2017 – March 2018)**

	Observed deaths (1)	$\Delta$ Mortality Rate [95% CI] (2)	Population (100,000's) (3)	Expected Deaths (4)	Excess Deaths (5)	Ratio of Observed to Expected Mortality (6)
<b>Panel A: 0-39 Years of Age</b>						
<b>Men</b>	936	-0.023 (-0.026, -0.019)	18.782	957.6	-22 (-23, -20)	0.98 (0.98, 0.98)
<b>Women</b>	433	0.011 (-0.106, 0.129)	17.635	428.2	5 (-18, 28)	1.01 (0.96, 1.07)
<b>Panel B: 40-64 Years of Age</b>						
<b>Men</b>	2320	-0.005 (-0.016, 0.005)	7.626	2332.5	-12 (-24, -1)	0.99 (0.99, 1.00)
<b>Women</b>	1276	-0.041 (-0.086, 0.004)	7.967	1329.1	-53 (-80, -26)	0.96 (0.94, 0.98)
<b>Panel C: <math>\geq</math> 65 Years of Age</b>						
<b>Men</b>	4249	0.073 (0.008, 0.137)	2.222	3950.9	298 (182, 414)	1.08 (1.04, 1.11)
<b>Women</b>	4796	0.064 (0.041, 0.088)	3.002	4498	298 (250, 346)	1.07 (1.05, 1.08)
<b>Panel D: All</b>						
<b>Men</b>	7505	0.036 (0.022, 0.050)	28.63	7241	264 (162, 366)	1.04 (1.02, 1.05)
<b>Women</b>	6505	0.039 (0.028, 0.050)	28.604	6255	250 (179, 320)	1.04 (1.03, 1.05)

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**Table 3: Excess Mortality of the Puerto Rican Population Ages 65 and Older in the Mainland U.S., by Education Group and Sex (October 2017 – March 2018)**

	Observed deaths (1)	$\Delta$ Mortality Rate [95% CI] (2)	Population (100,000's) (3)	Expected Deaths (4)	Excess Deaths (5)	Ratio of Observed to Expected Mortality (6)
<b><i>October 2017 - March 2018</i></b>						
<b>Panel A: 65+ Years of Age, High School Dropouts</b>						
<b>Men</b>	1,802	0.121 (-0.110, 0.352)	0.911	1,597	205 (37, 373)	1.13 (1.01, 1.25)
<b>Women</b>	2,232	0.115 (0.017, 0.214)	1.168	1,989	243 (154, 332)	1.12 (1.07, 1.17)
<b>Panel B: 65+ Years of Age, High School Graduates</b>						
<b>Men</b>	1,560	0.119 (0.044, 0.195)	0.591	1,385	175 (127, 223)	1.13 (1.09, 1.17)
<b>Women</b>	1,565	0.012 (-0.033, 0.058)	0.884	1,546	19 (-13, 51)	1.01 (0.99, 1.03)
<b>Panel C: 65+ Years of Age, Some College or More</b>						
<b>Men</b>	774	0.082 (0.015, 0.15)	0.7	712.8	61 (39, 83)	1.09 (1.05, 1.12)
<b>Women</b>	896	0.121 (0.087, 0.155)	0.929	794.2	102 (89, 114)	1.13 (1.11, 1.15)

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3 (95% CI 89-114) excess deaths among old age men and women respectively with at least some  
4 higher education.  
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## 8 **V. Discussion**

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12 Our study emphasizes the importance of considerations of displacement in the calculation of post-  
13 disaster excess mortality. These displaced populations are frequently overlooked in the context of  
14 both disaster relief and the subsequent research, and we argue that ignoring these populations  
15 provides an incomplete understanding of the magnitude of the damages and loss of life.  
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20 Our empirical framework leverages comparator populations of Cuban and Mexican in the  
21 mainland U.S, whose countries of origin were unaffected by Hurricane Maria, but had otherwise  
22 similar mortality trends to account for differential mortality among the Puerto Rican population.  
23 This methodology is thus applicable both in other countries and in other disaster contexts (both  
24 natural and otherwise), particularly as displacement and mobility becomes an increasingly  
25 important feature of natural disasters.<sup>17</sup>  
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32 While official government estimates of mortality in Puerto Rico were low, reflecting only deaths  
33 directly attributable to the Hurricane, excess mortality measures for the six-month period following  
34 the disaster were as high as 2,975.<sup>7</sup> Our findings suggest that these measures may be  
35 underestimating total excess mortality by an additional 514 deaths (95% CI 346 – 681). In the six  
36 months following the passing of Hurricane Maria, we show that individuals of Puerto Rican origin  
37 in the mainland U.S saw an increased excess mortality. Crucially, this growth in mortality was  
38 concentrated among the most vulnerable populations, with old age adults with lower levels of  
39 education seeing the largest increases. These patterns are consistent with excess mortality  
40 estimates obtained in Puerto Rico.  
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50 Our study is informative regarding the broad mortality consequences of the disaster among the  
51 displaced population of Puerto Rico in the U.S. This measure however limits our ability to quantify  
52 the elevated burden of disease from morbidity and disability among the displaced population. We  
53 were also unable to precisely measure cause-specific mortality causes or the causal pathways for  
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3 such trends. Given the relatively small numbers of deaths in the population in the period under  
4 observation (monthly range 2,119–2,862), informative estimates of more finely defined cause-  
5 specific mortality rates were not possible. This remaining important research requires future work.  
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## 8 **VI. Conclusion**

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11 This analysis suggests the need for not only equitable disaster preparedness, but also the  
12 importance of cross-jurisdiction cooperation.<sup>7</sup> These already vulnerable populations may face a  
13 number of additional hurdles upon relocation, such as healthcare disruptions and psychological  
14 stressors which may exacerbate health impacts of the disaster. Receiving jurisdictions would, thus,  
15 benefit from an improved understanding of both the dynamics of post-disaster displacement, and  
16 its consequences. Our results may also shed light on the discrepancies between survey-based and  
17 other studies using vital records to estimate the Hurricane Maria death toll in Puerto Rico.<sup>7</sup>  
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26 Already important efforts exist among jurisdictions in the U.S., such as the State and Territorial  
27 Exchange of Vital Events (STEVE) of the National Association for Public Health Statistics  
28 Information Systems (NAPHSIS), to facilitate vital records for use by other state-level and  
29 territorial public health organizations. However, more coordination is required to speed the flow  
30 of data to gain a more comprehensive understanding of the scale of disasters in other countries.  
31 Moreover, even among jurisdictions within the U.S., this process can take a considerable amount  
32 of time. The speed of flow of vital records depends on the effectiveness of local and county vital  
33 registrars to share this information. Ensuring timely exchange of death records among jurisdictions  
34 would ensure disaster death toll estimates based on vital records are complete and would hence  
35 allow public authorities to have a comprehensive understanding of the scale of the disaster in a  
36 timely fashion.  
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51 <sup>7</sup> Kishore et al. (2018) surveyed a representative sample of households, asking survivors to account for the whereabouts of all  
52 people that lived in their community prior to the Hurricane, irrespective of the location of the occurrence of death of relatives and  
53 family members, on the island or elsewhere.<sup>30</sup> As such, we would expect excess mortality estimates based on vital records of the  
54 deaths occurring in Puerto Rico to yield lower estimates than a survey-based method that does not restrict death occurrences to  
55 Puerto Rico. They found a mortality rate that yielded an estimate of 4,645 excess deaths (95% CI 793-8498) on account of Hurricane  
56 Maria. This is notably higher than the estimates prepared using vital records. Our excess mortality estimates of the Puerto Rican  
57 population in the U.S. suggest that part of the Hurricane Maria death toll took place off the island, and as such can explain part of  
58 the difference in estimates between the survey-based estimate and the estimates based on vital records.

## **Ethics statements**

### **Patient consent for publication**

Not required.

### **Ethics approval**

Because these data are publicly available and deidentified, this study is considered to be research not involving human subjects as defined by U.S. regulation (45 CFR 46.102[d]).

### **Contributorship Statement:**

MM: conceptualisation, data curation, supervision, validation, visualisation, writing – original draft, and writing – review & editing.

BM: conceptualisation, data curation, formal analysis, investigation, methodology, visualisation, writing – original draft, and writing – review & editing.

GB: conceptualisation, formal analysis, investigation, methodology, project administration, supervision, validation, visualisation, writing – original draft, and writing – review & editing.

**Competing Interests:** Neither author has any competing interests to declare.

**Funding Statement:** None

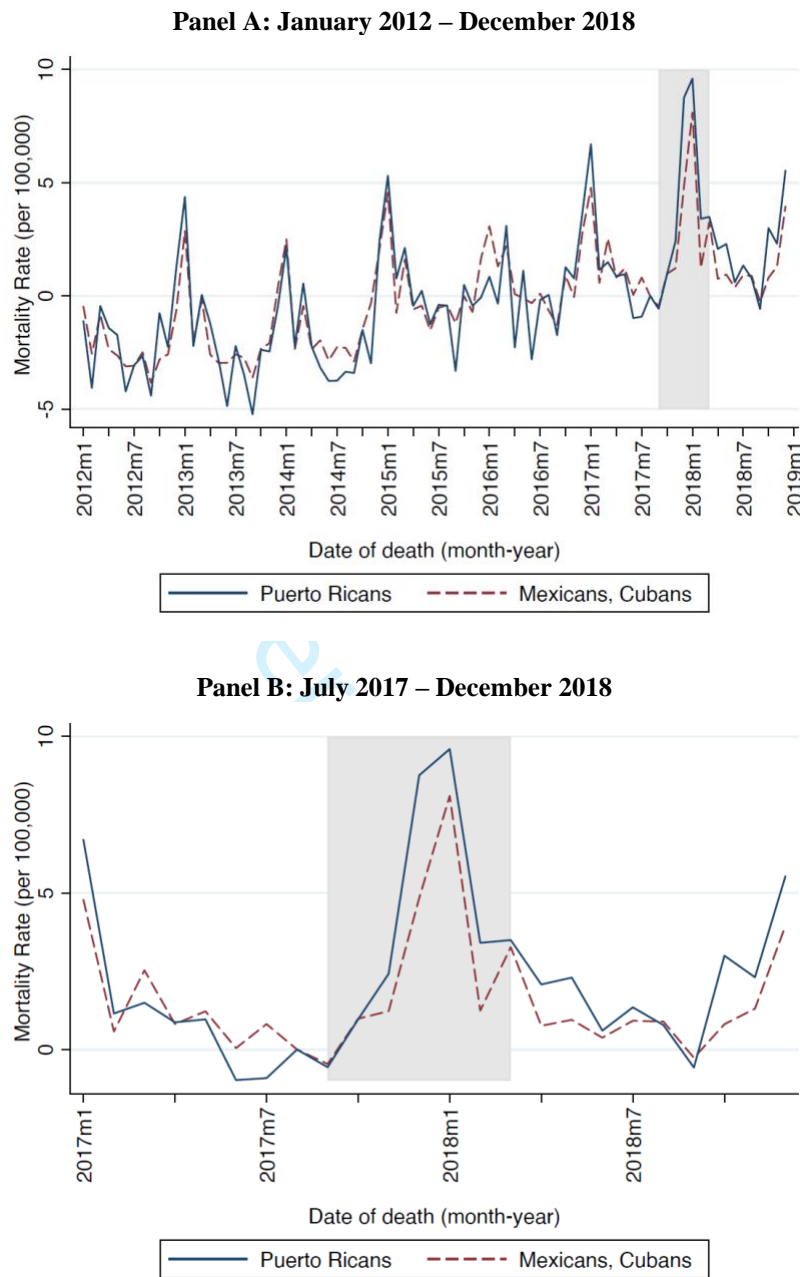
### **Data Sharing statement**

All data relevant to the study are publicly available (and detailed in the article and supplementary materials).

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**Figure 1: Standardized Monthly Mortality Rate of Puerto Ricans vs. Cubans and Mexicans in the US**

Notes: Standardized monthly mortality from January 2012 to December 2018 (Panel A) and from July 2017 to December 2018 (Panel B). August 2017 is used as the standard mortality rate for both populations.

**Supplementary Materials****A. Additional Figures and Tables****Table A1. Excess Mortality Estimates of Hurricane Maria<sup>1-5</sup>**

Paper	Preferred Excess Mortality Estimate
Santos-Lozada A, Howard JT. (2018)	1,139 ± 133
Santos-Burgoa C. et al. (2018)	2,975 ± 317
Acosta R, Irizarry, R. (2018)	3,400 ± 300
Cruz-Cano R, Mead E. (2019)	1,205 ± 498
Rivera R, Rolke W. (2019)	1,318 ± 249



## B. Methods

### B.1. Temporal Disaggregation of Population Estimates

Annual population estimates of Puerto Ricans, Mexicans and Cubans in the United States were disaggregated to a monthly frequency using the Chow-Lin maxlog method.<sup>6,7</sup> This standard method of temporal disaggregation derives the high-frequency (monthly) data from low frequency (annual) data, allowing for the use of related high-frequency data which the researcher has reason to believe is related to the target time series. In applying this method, the researcher is able to create a high frequency dataset consistent with the initial low-frequency data, but which incorporates the short-term volatility of the related high-frequency data.<sup>1</sup> This is done through a standard least-squares estimation, where the error term is assumed to follow an AR(1) process. In our disaggregation, we chose not to impose a particular short-term volatility, and so regress our low-frequency data for each age-sex-education-Hispanic strata on a constant term, with a mean conversion.

### B.2. Estimation of Excess Mortality Levels – Overall and by Subgroup

Our estimation procedure uses the observed age-group-by-gender specific deaths that occurred over the period of September 2018 until March 2018 as well as our estimated coefficients of the differential change in mortality rates of Puerto Ricans in the mainland US ( $\theta_s$  and  $\theta_{st}$ ), to construct estimates of excess mortality for each age-group-gender combination and their corresponding 95 percent confidence interval. To do this:

1. We first obtain the estimates of  $\theta_s$  and  $\theta_{st}$  separately each age-group-gender combination.
2. We then estimate expected deaths following Maria for each of these subgroups using a non-linear combination of our estimates of the change in mortality rates and the observed deaths. Using nonlinear estimation, we estimate the expected deaths of an age-group-gender combination to be equal to  $\exp(\ln(\text{Observed Deaths}_s) - \theta_s)$ . This is also performed using the period-specific effects ( $\theta_{st}$ ) and observed deaths. This nonlinear estimation procedure also produces standard errors, which are used to construct confidence intervals.
3. We estimate excess deaths by subtracting the expected deaths estimated in (2) from the observed mortality rates for each age-group-gender combination.
4. Finally, to construct the ratio of observed to expected mortality we divide the observed deaths for each age-group-gender combination by our estimate of expected mortality in (2).

To aggregate our age-group-by-gender results to the overall population, we follow a similar procedure.

1. Estimate, as before, our main specification, to obtain a  $\theta_s$  for each of the three age-groups.
2. Aggregate the age group-gender-specific observed deaths to measures at the desired level of aggregation.
3. We then estimate expected deaths following Maria for each of these subgroups using a non-linear combination of our estimates of the change in mortality rates and the observed deaths. Using nonlinear estimation, we calculate, more specifically, the expected deaths of the group,  $h$ , combination to be equal to  $\Sigma_h \exp(\ln(\text{Observed Deaths}_h) - \theta_{sh})$ . This nonlinear estimation procedure also generates standard errors, which are used to construct confidence intervals.
4. Estimate the implied excess deaths by subtracting the expected deaths in (2) from the observed deaths for each age-group:  $\Sigma_h (\text{Observed Deaths}_h) - \Sigma_h \exp(\ln(\text{Observed Deaths}_h) - \theta_{sh})$ .
5. Construct the ratio of observed to expected mortality using the aggregated observed deaths from (2) and the estimated aggregate expected deaths from (3).

### B.3. Estimation of Population Displacement – Overall and by Subgroup

An important consideration in this analysis is our need to estimate the degree of population displacement of the residents of Puerto Rico to the mainland U.S. following the hurricanes. We do so by measuring differential changes in population levels for the Puerto Rican population in the mainland U.S. relative to trends for the comparison groups throughout the period following the Hurricanes.

Again, we make these comparisons by gender and age group, and estimate a system of linear models of the form:

$$\ln(\text{Pop}_{sgmt}) = \tau_s(\text{Maria}_{mt} \times \text{PR}_{sg}) + \mu_{sg} + \delta_{mt} + v_{sgmt}, \quad (\text{B1})$$

where the main outcome and explanatory variables as defined above;  $\mu_{sg}$  are Hispanic group fixed effects;  $\delta_{mt}$  are month-by-year fixed effects; and  $v_{sgmt}$  is the error term; we employ the same estimation procedure. We follow an analogous estimation and aggregation procedure to generate estimates of group-specific and aggregate levels of population displacement in the six-month period following the Hurricane (see Appendix B2 for details). This

<sup>1</sup> [https://ec.europa.eu/eurostat/cros/content/chow-lin-method-temporal-disaggregation-method\\_en](https://ec.europa.eu/eurostat/cros/content/chow-lin-method-temporal-disaggregation-method_en)

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3 procedure allows us to both confirm independent estimates of population movements from the territory to the mainland  
4 U.S. during this period and to give confidence to the use of population estimates for the estimation of excess mortality  
5 rates.  
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7 Population displacement was concentrated among the population of individuals ages 65 and older (Table B.1). The  
8 population for this group was higher than the expected pattern throughout the October 2017-March 2018 period: the  
9 point estimates imply a population increase of 6·0 percent among men (95% CI 1·02 – 1·11 percent) and of 9·7 percent  
10 among women (95% CI 1·04 – 1·17 percent) for women. In terms of the temporal pattern, we detect increases in  
11 population levels of 2·5 and 14·6 percent among both older age women and men starting in November 2017 until  
12 March 2018, with consistently greater statistical precision among the former group.<sup>2</sup> In contrast, we find no robust  
13 evidence of increases in population from the expected pattern for the younger age populations throughout this period.  
14 These estimates are consistent with existing evidence that a large share of the post-disaster displacement among the  
15 Puerto Rico-based population occurred among the elderly.<sup>2</sup>  
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56 <sup>2</sup> Results available upon request from corresponding author.  
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**Table B.1:** Estimates of Displacement of Puerto Rican Population to the Mainland US, by Age Group and Sex (October 2017 – March 2018)

	$\Delta \ln(\text{Population})$ [95% CI] (1)	Population (100,000's) (2)	Expected Pop. (3)	Excess Pop. (4)	Ratio of Observed to Expected Population (5)
<b>Panel A: 0-39 Years of Age</b>					
<b>Men</b>	0.000 (-0.218, 0.218)	18.782	18.783	-0.001 (-1.869, 1.868)	1.00 (0.90, 1.10)
<b>Women</b>	-0.031 (-0.239, 0.178)	17.635	18.189	-0.554 (-2.282, 1.174)	0.97 (0.87, 1.06)
<b>Panel B: 40-64 Years of Age</b>					
<b>Men</b>	0.000 (-0.061, 0.061)	7.626	7.625	0.001 (-0.211, 0.213)	1.00 (0.97, 1.03)
<b>Women</b>	-0.004 (-0.024, 0.016)	7.967	8.000	-0.033 (-0.107, 0.042)	1.00 (0.99, 1.01)
<b>Panel C: ≥ 65 Years of Age</b>					
<b>Men</b>	0.060 (-0.037, 0.157)	2.222	2.092	0.130 (0.037, 0.222)	1.06 (1.02, 1.11)
<b>Women</b>	0.097 (-0.037, 0.231)	3.002	2.275	0.277 (0.111, 0.443)	1.10 (1.04, 1.17)
<b>Panel D: All</b>					
<b>Men</b>	0.005 (-0.052, 0.061)	28.630	28.500	0.130 (-1.482, 1.742)	1.01 (0.95, 1.06)
<b>Women</b>	-0.011 (-.057, .035)	28.604	28.913	-0.309 (-1.636, 1.017)	0.99 (.94, 1.04)

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60STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

	<b>Item No</b>	<b>Recommendation</b>	
<b>Title and abstract</b>	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	Page 1, Title
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	Page 1, Summary
<b>Introduction</b>			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Page 2, Paragraph 1-3
Objectives	3	State specific objectives, including any prespecified hypotheses	Page 2, Paragraph 4
<b>Methods</b>			
Study design	4	Present key elements of study design early in the paper	Page 3, Paragraph 1
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Page 1, Summary
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants	Page 3, Section II, Paragraph 1
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Page 3, Section II, Paragraph 1-2
Data sources/measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Page 3, Section II, Paragraph 1-2
Bias	9	Describe any efforts to address potential sources of bias	Page 4 paragraph 2-3, page 5 paragraph 1
Study size	10	Explain how the study size was arrived at	n/a
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Page 3, Section II, Paragraph 2
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	Page 4, Section III
		(b) Describe any methods used to examine subgroups and interactions	Page 4, Section III, Paragraph 1
		(c) Explain how missing data were addressed	Page 3, Section II, Paragraph 3
		(d) If applicable, describe analytical methods taking account of sampling strategy	N/A
		(e) Describe any sensitivity analyses	N/A
<b>Results</b>			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the	Page 5, Section IV, Paragraph 1

		study, completing follow-up, and analysed	
		(b) Give reasons for non-participation at each stage	n/a
		(c) Consider use of a flow diagram	n/a
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Page 5, Section IV, Paragraph 1
		(b) Indicate number of participants with missing data for each variable of interest	N/A
Outcome data	15*	Report numbers of outcome events or summary measures	Page 5, Section IV, Paragraph 1
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Page 5, Section IV
		(b) Report category boundaries when continuous variables were categorized	Page 3, Section II, paragraph 5
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Page 4 paragraph 6
<b>Discussion</b>			
Key results	18	Summarise key results with reference to study objectives	Page 6, paragraph 3
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Page 6, paragraph 4
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Page 6
Generalisability	21	Discuss the generalisability (external validity) of the study results	Page 6, paragraph 2
<b>Other information</b>			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	N/A

\*Give information separately for exposed and unexposed groups.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at [www.strobe-statement.org](http://www.strobe-statement.org).

# BMJ Open

## Mortality of Puerto Ricans in the United States Post-Hurricane Maria: An Interrupted Time Series Analysis

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3 1 **Mortality of Puerto Ricans in the United States Post-Hurricane Maria: An Interrupted Time**  
4 2 **Series Analysis**  
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11 9 Mario Marazzi, PhD<sup>1</sup>, Boriana Miloucheva, MA<sup>2</sup>, and Gustavo Bobonis, Ph.D<sup>3</sup>  
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16 **Manuscript Word Count: 3900**

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3 40 **Mortality of Puerto Ricans in the United States Post-Hurricane Maria: An Interrupted Time**  
4 41 **Series Analysis**  
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7 43 ***Abstract***

9 44 *Objectives:* To determine death occurrences of Puerto Ricans on the mainland U.S. following the  
10 45 arrival of Hurricane Maria in Puerto Rico in September 2017.

12 46 *Design:* Cross-sectional study

14 47 *Participants:* Persons of Puerto Rican origin on the mainland United States

16 48 *Exposures:* Hurricane Maria

18 49 *Main Outcome:* We use an interrupted time-series design to analyze all-cause mortality of Puerto  
19 50 Ricans in the U.S. following the Hurricane. Hispanic Origin data from the National Vital Statistics  
20 51 System and from the Public Use Microdata Sample of the American Community Survey are used  
21 52 to estimate monthly origin-specific mortality rates for the period 2012 to 2018. We estimated log-  
22 53 linear regressions of monthly deaths of persons of Puerto Rican origin by age group, gender, and  
23 54 educational attainment.

25 55 *Results:* We found an increase in mortality for persons of Puerto Rican origin during the 6-month  
26 56 period following the Hurricane (October 2017 through March 2018), suggesting that deaths among  
27 57 these persons were 3·7% (95% CI: 0·025-0·049) higher than would have otherwise been expected.  
28 58 In absolute terms, we estimated 514 excess deaths (95% CI 346 – 681) of persons of Puerto Rican  
29 59 origin that occurred on the mainland U.S., concentrated in those aged 65 years or older.

31 60 *Conclusions:* Our findings suggest an undercounting of previous deaths as a result of the hurricane  
32 61 due to the systematic effects on the displaced and resident population in the mainland U.S.  
33 62 Displaced populations are frequently overlooked in disaster relief and subsequent research.  
34 63 Ignoring these populations provides an incomplete understanding of the damages and loss of life.

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3 764  
5 776 78 *Article Summary*7  
8 79 *Strengths and limitations*

- 9  
10 80 • One of the first studies to examine excess mortality among migrant and displaced  
11 81 populations following a natural disaster.
- 12 82 • Leverage comparison group mortality outcomes to control for seasonality and period-  
13 83 specific effects, minimizing potential confounding.
- 14 84 • As the mortality outcomes are aggregated at the Hispanic group and gender-age group  
15 85 stratum in each month, we are unable to precisely measure cause-specific mortality.
- 16 86 • Our analysis does not allow us to disentangle the excess mortality of displaced populations  
17 87 as opposed to longer-term migrants or second or third-generation individuals of such  
18 88 ancestry.

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## 1. Introduction

Extreme weather events such as hurricanes are growing in frequency and magnitude and are expected to affect a growing population due to migration patterns, ecosystem alteration, and climate.<sup>1,2</sup> The consequences for human lives and the economic costs associated with these disasters are high.<sup>3,4</sup> While much research documents the direct impacts of natural disasters on the mortality, morbidity, and socioeconomic consequences of populations in affected areas, substantially less attention has been paid to the consequences for populations displaced as a result of these events.<sup>3,5,6</sup>

While all victims of natural disasters face common challenges, displaced populations undergo distinct experiences that are specific to their relocation—such as additional psychological stressors and disruption in access to healthcare services as well as changes in their living conditions and social networks.<sup>1</sup> These circumstances can either compound or mitigate the effects of disasters for these populations. Consistent with the heterogeneity in the populations' experiences, a growing body of research finds mixed evidence regarding the incidence and extent of higher mortality risk among displaced populations.<sup>2</sup>

However, measuring the mortality consequences of disasters among these populations is inherently challenging due to the displacement that can take place before, during or in the aftermath of an event.<sup>3</sup> Few studies of displaced populations have analyzed representative sample data before and after exposure to a disaster relative to comparable populations to be able to credibly measure the effects of these events.<sup>4</sup> In spite of these methodological limitations, this literature has shaped our understanding of mortality patterns among displaced populations. If conclusions about these forms

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<sup>1</sup> See Uscher-Pines and Frankenberg, Laurito, and Thomas for systematic reviews of the literatures on the health effects of relocation following disaster and of the demographic consequences of disasters more generally.<sup>20,21</sup>

<sup>2</sup> In an early systematic review of the literature, Uscher-Pines documents no short nor long-term consequences on mortality for displaced populations following post-disaster relocation.<sup>21</sup> Subsequent studies find higher mortality risks for specific displaced subpopulations such as among relocated institutionalized elderly; see Willoughby et al. for a systematic review.<sup>22</sup>

<sup>3</sup> Most data on disasters are obtained from those who remain relatively near the site of the disaster or who have relocated to obvious camps and refugee settlements. The mortality of the rest of the displaced population may be missed if proper attention is not taken in the design of data collection efforts. Furthermore, displacement makes it difficult to know how completely those interviewed represent the underlying population exposed to the event, nor is it possible to benchmark respondents' experiences during and after an event against their circumstances before the event, or against populations that were not exposed to the event but are otherwise similar.<sup>6,23</sup>

<sup>4</sup> Specifically, studies of populations after large-scale disasters typically describe the experiences of particular groups of individuals—such as those displaced to specialized refugee locations—providing little information about individuals who settled elsewhere, although there are exceptions.<sup>6,19,20,23–28</sup>

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3 114 of vulnerability do not transcend specific groups and cannot be replicated more generally, their  
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5 115 informativeness in planning for or responding to the needs of at-risk populations—monitoring,  
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7 116 assessment, programming of interventions and the targeting of social safety nets—is compromised.  
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10 118 In this article, we contribute to research on the mortality consequences of extreme environmental  
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12 119 hazards among displaced populations in host communities.<sup>5</sup> Our objective is to estimate the excess  
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14 120 mortality experienced by Puerto Ricans in the mainland U.S. following the devastation caused in  
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16 121 Puerto Rico by Hurricanes Irma and Maria in September 2017. The consensus from existing  
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18 122 research documenting excess mortality in the aftermath of the Hurricanes—based on death  
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20 123 occurrences that happened physically in the archipelago of Puerto Rico—is that well over one  
21  
22 124 thousand people died in Puerto Rico and likely more than three thousand lost their lives (see  
23  
24 125 Supplementary Materials Table A1).<sup>7–11</sup> However, to date, no systematic attempt had been made  
25  
26 126 to consider deaths that may have occurred on the mainland United States as a result of this natural  
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28 127 disaster. To our knowledge, this is the first study to explicitly examine the post-disaster death  
29  
30 128 occurrences of Puerto Ricans in the mainland U.S.

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32 130 We combine administrative death records data from the U.S. National Vital Statistics System  
33  
34 131 together with population estimates using repeated cross-sections of the Public Use Microdata  
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36 132 Sample of the American Community Survey to estimate monthly immigrant-origin group-specific  
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38 133 mortality rates by age, gender, and educational attainment for the period 2012 to 2018 in the  
39  
40 134 mainland U.S. Using these data, which is representative of the at-risk population, we conduct  
41  
42 135 analyses that measure outcomes consistently for individuals from the group affected by the disaster  
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44 136 relative to those of comparable populations. We use an interrupted time-series differences-in-  
45  
46 137 differences design to examine patterns of all-cause mortality of Puerto Ricans in the United States  
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48 138 during the months following the Hurricane, using mortality trends for Cuban and Mexican  
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50 139 populations in the mainland U.S.—whose countries of origin or ancestry were not affected by  
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52 140 extreme hurricanes that year (or limited population displacement to the U.S. as a result of these  
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54 141 events) and who had historically similar mortality trends preceding the event—as a comparison  
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56 142 group.

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55 <sup>5</sup> We conceptualize post-disaster mobility as a coping strategy that occurs along a spectrum from forced displacement to largely  
56 voluntary migration.<sup>6,29–31</sup>

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5 144 Identifying the existence and magnitude of a period of excess mortality among Puerto Ricans in  
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7 145 the United States in the months following the passage of Hurricane Maria over Puerto Rico would  
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9 146 support the hypothesis that displaced and migrant populations also face a higher risk of mortality  
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11 147 and possibly other health consequences from exposure to such natural disasters.  
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## 14 149 **2. Methods**

### 15 150 **2.1 Data and Descriptive Statistics**

16  
17 151 We use publicly available microdata from the National Vital Statistics System of the National  
18  
19 152 Center for Health Statistics to identify deaths of persons of Puerto Rican origin on the mainland  
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21 153 United States between 2012 and 2018. The data also allows us to identify deaths of persons of  
22  
23 154 other Hispanic origins, which we use as a comparison group. It also includes the month of  
24  
25 155 occurrence, as well as several socio-economic variables for each death, including the person's age,  
26  
27 156 gender, and educational attainment.  
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29 158 We use the Public Use Microdata Sample of the American Community Survey (ACS) of the U.S.  
30  
31 159 Census Bureau to estimate the annual population of each Hispanic origin, for each age group,  
32  
33 160 gender, and educational attainment between 2012 and 2018. Following Santos Burgoa et al.  
34  
35 161 (2018), age was categorized in three groups: 0-39 years, 40-64 years, and 65 years or older. For  
36  
37 162 age groups 40-64 years and 65 years and older, we also stratified the sample in three groups based  
38  
39 163 on individuals' educational attainment: persons who did not complete high school, those with only  
40  
41 164 a high school degree, and those with some higher education or more.  
42

43 166 We employ a standard temporal disaggregation method for time series data based on dynamic  
44  
45 167 models to generate stratum-specific population measures for each month.<sup>12,13</sup> The technique  
46  
47 168 exploits the time-series relationship of the available low-frequency data using a regression model  
48  
49 169 with autocorrelated errors generated by a first-order autoregressive process. The reference period  
50  
51 170 of the ACS is the 12-month calendar year. As a result, we also restrict the 12-month average  
52  
53 171 population estimate to equal the annual ACS-based population estimate; see Supplementary  
54  
55 172 Materials for details.  
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3 174 Because these data are publicly available and deidentified, this study is considered to be research  
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5 175 not involving human subjects as defined by U.S. regulation (45 CFR 46.102[d]).  
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## 8 177 **2.2 Patient and Public Involvement**

9  
10 178 No patients involved.  
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## 13 180 **2.3 Statistical Analysis**

14  
15 181 Our empirical strategy consists of an interrupted time series / difference-in-differences design. We  
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17 182 compare differences in the gender-by-age group stratum mortality rates of Puerto Ricans before  
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19 183 and after September 2017 relative to that of Cubans and Mexicans, comparable Hispanic groups  
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21 184 in the U.S., during the January 2012-December 2018 time period. In doing so, we effectively use  
22  
23 185 the mortality outcomes of the comparison groups to control for seasonality and period-specific  
24  
25 186 effects. We make these comparisons by gender-by-age group, estimating a system of six (6) linear  
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27 187 models of the form:  
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$$29 \quad 189 \quad \ln(d_{sgmt}) = \theta_s(\text{Maria}_{mt} \times \text{PR}_{sg}) + \beta_s \ln(\text{Pop}_{sgmt}) + \alpha_{sg} + \gamma_{mt} + \varepsilon_{sgmt}, \quad (1)$$

30  
31 190  
32 191 where  $d_{sgmt}$  is the number of deaths of individuals from gender-age group stratum  $s$  and Hispanic  
33  
34 192 group  $g$  in month  $m$  and year  $t$ ;  $\text{Maria}_{mt}$  is an indicator variable for the 6-month period from October  
35  
36 193 2017 to the March 2018;  $\text{PR}_{sg}$  is an indicator variable for Puerto Rican origin;  $\text{Pop}_{sgmt}$  is the  
37  
38 194 population level estimate for each Hispanic group  $g$  over time;  $\alpha_{sg}$  are Hispanic group fixed effects;  
39  
40 195  $\gamma_{mt}$  are month-by-year fixed effects; and  $\varepsilon_{sgmt}$  is the error term. This model richly captures  
41  
42 196 seasonality as well as other time trends for each gender-by-age stratum, and accounts for  
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44 197 differences in the mortality rate levels between Puerto Ricans and other Hispanic groups. We  
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46 198 estimate the models as a system of equations allowing for autocorrelation of the error terms by  
47  
48 199 clustering standard errors at the Hispanic group level.<sup>14-16</sup> This procedure also allows us to account  
49  
50 200 for the correlation of mortality rates across age groups and gender within each Hispanic group as  
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52 201 well as the autocorrelation of mortality for each group, and to generate estimates of aggregate  
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54 202 excess mortality for the population based on the stratum-specific models.  
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3 204 We also report a series of estimates from an event study to document the month-specific effects of  
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5 205 the Maria shock. Specifically, we estimate equation (2) to explore this:  
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$$8 \quad 207 \quad \ln(d_{sgmt}) = \theta_{st} \cdot \mathbf{I}\{g = \text{PR}_g\} \cdot \mathbf{I}\{t = 1, 2, \dots, 6\} + \beta_s \ln(\text{Pop}_{sgmt}) + \alpha_{sg} + \gamma_{mt} + \varepsilon_{sgmt}, \quad (2)$$

10 208  
11  
12 209 where  $\mathbf{I}\{g = \text{PR}_g\} \cdot \mathbf{I}\{t = 1, 2, \dots, 6\}$  is a vector capturing the interaction of the PR indicator with an  
13  
14 210 indicator variable for each month from October 2017 to March 2018, with September 2017 – the  
15  
16 211 month of the event – as the base period. All other variables are as defined above in equation (1).  
17  
18 212 The vector  $\theta_{st}$  captures the period-specific effects for each month during the 6-month window  
19  
20 213 described earlier.  
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24 215 Our estimation procedure uses the observed age-group-by-gender specific deaths that occurred  
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26 216 over the period of October 2017 until March 2018 as well as our estimated coefficients of the  
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28 217 differential change in mortality rates of Puerto Ricans in the mainland U.S. ( $\theta_s, \theta_{st}$ ), to construct  
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30 218 estimates of excess mortality for each age-group-sex combination and their corresponding 95  
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32 219 percent confidence interval. We follow an analogous procedure to generate estimates of excess  
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34 220 mortality for the population in overall terms. See Supplementary Materials for details of the  
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36 221 estimation and aggregation procedures.  
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40 223 An important consideration in this analysis is our need to estimate the degree of population  
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42 224 displacement of the residents of Puerto Rico to the mainland U.S. following the hurricanes. We do  
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44 225 so by measuring differential changes in population levels for the Puerto Rican population in the  
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46 226 mainland U.S. relative to trends for the comparison groups throughout the period following the  
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48 227 Hurricanes. This methodology, described in more detail the Supplementary Materials, generates  
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50 228 estimates of population displacement, or the population in excess of what would have otherwise  
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52 229 been expected. This procedure allows us to both confirm independent estimates of population  
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54 230 movements from the territory to the mainland U.S. during this period and to give confidence to the  
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56 231 use of population estimates for the estimation of excess mortality rates.  
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## 58 232 59 233 **IV. Results**



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3 234 14,010 individuals of Puerto Rican background died in the mainland U.S. between October 2017  
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5 235 and March 2018 (Table 1); 7,505 (53.6%) were men and 6,505 (46.4%) were women (Table 2);  
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7 236 9,045 (64.6%) were adults aged 65 years or older (Table 3). In contrast, between 10,866 and 12,832  
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9 237 deaths occurred among this population in the six-month period between October and March in the  
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11 238 2012-13 to 2016-17 years, the period of observation before the hurricane. We estimated that there  
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13 239 were approximately 5.631 million individuals of Puerto Rican origin in the mainland U.S. in  
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15 240 August 2017, and by March 2018, this number was 5.783 million—an increase of approximately  
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17 241 152,000 individuals, or a 2.7 percent population increase (Table 1).  
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21 243 We compare mortality outcomes pre and post September 2017 among the Puerto Rican population  
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23 244 in the mainland U.S. relative to other Hispanic groups in the country. In Panel A of Figure 1 we  
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25 245 examine trends in the overall mortality rate of Puerto Ricans in the mainland U.S. (blue solid line)  
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27 246 during January 2012-December 2018 and that of Cubans and Mexicans (red dashed line)  
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29 247 throughout the same period. Between January of 2012 and August 2017, the mortality rate among  
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31 248 individuals of Puerto Rican origin averaged 280.89 per 100,000. In contrast, the mortality rate  
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33 249 among Cubans and Mexicans throughout this period was 232.17 per 100,000. In spite of this  
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35 250 difference in mortality levels, the two groups experienced very similar mortality seasonal patterns  
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37 251 and trends in the period up to September 2017, when Puerto Rico was severely affected by  
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39 252 Hurricanes Irma and Maria (Figure 1, Panel A).  
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43 254 Following these events, we observe a modest trend break in the mortality rate of Puerto Ricans  
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45 255 relative to that of Cubans and Mexicans, in the 0.08-4.03 deaths per 100,000 range (Figure 1,  
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47 256 Panel B). The figure helps validate the research design.<sup>6</sup> Moreover, it reveals the mortality rate  
48  
49 257 gap to be most pronounced during the October 2017 through March 2018; we use this post-  
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51 258 Hurricane six-month event window to capture estimates of excess mortality for the Puerto Rican  
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53 259 population in the mainland U.S.

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55 <sup>6</sup> In the Supplemental Appendix, we include a series of placebo tests we performed to evaluate whether there are significant  
56 increases in mortality of the Puerto Rican population relative to that of the comparison group pre-October 2017, which confirm the  
57 common trends assumption.

**Table 1: Excess Mortality of the Puerto Rican Population in the Mainland U.S., Overall and by Month (October 2017 – March 2018)**

	Observed Deaths (1)	$\Delta$ Mortality Rate [95% CI] (2)	Population (100,000's) (3)	Expected Deaths (4)	Excess Deaths [95% CI] (5)	Ratio of Observed to Expected Mortality [95% CI] (6)
<b>Panel A: Month-Specific Estimates</b>						
October 2017	2,093	0.022 (-0.006, 0.051)	56.596	2,047	46 (-11.7, 104.1)	1.02 (0.99, 1.05)
November 2017	2,182	0.059 (0.041, 0.078)	56.767	2,056	126 (87.1, 164.7)	1.06 (1.04, 1.08)
December 2017	2,551	0.065 (0.048, 0.082)	56.974	2,391	160 (119.4, 200.7)	1.07 (1.05, 1.09)
January 2018	2,624	0.012 (-0.014, 0.039)	57.524	2,592	32 (-36.1, 100.5)	1.01 (0.99, 1.04)
February 2018	2,275	0.059 (0.035, 0.083)	57.708	2,145	130 (78.1, 182.4)	1.06 (1.03, 1.09)
March 2018	2,285	0.004 (-0.008, 0.016)	57.830	2,276	9 (-19.1, 36.8)	1.00 (0.99, 1.02)
<b>Panel B: Aggregate Estimates</b>						
October 2017 - March 2018	14,010	0.037 (0.025, 0.050)	57.233	13,496	514 (346.5, 681.0)	1.04 (1.03, 1.05)
October 2017 - December 2017	6,826	0.037 (0.024, 0.049)	56.779	6,581	245 (163.6, 326.9)	1.04 (1.02, 1.05)

Notes: Column 1 reports observed deaths of the Puerto Rican population in the mainland U.S., and column 3 reports estimates of the overall population of Puerto Ricans in the mainland. Column 2 reports estimates of the difference in the natural logarithm of the mortality of Puerto Ricans relative to Cubans and Mexicans based on the aggregation of OLS estimates from equation 2 (Panel A) and equation 1 (Panel B) estimated for each gender-by-age group, as well as 95 percent confidence intervals in parentheses. Columns 4, 5, and 6 respectively report estimates of expected deaths, excess deaths, and the ratio of observed to expected deaths calculated from observed deaths (col. 1) and estimates of changes in mortality rates (col. 2); 95 percent confidence intervals of the level of excess deaths and of the ratio of observed to expected deaths are reported in parentheses.

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2  
3 270 Our results span the six-month period following the passing of Hurricane Maria (October 2017 –  
4  
5 271 March 2018). We find a statistically significant increase in the mortality rate for persons of Puerto  
6  
7 272 Rican origin during this period of approximately 3·7 percent (95% CI 2·4 – 4·9 percent) higher  
8  
9 273 than would have otherwise been expected (see Table 1).<sup>7</sup> In absolute terms, this is equivalent to  
10  
11 274 514 excess deaths (95% CI 346 – 681) of persons of Puerto Rican origin that occurred on the  
12  
13 275 mainland United States.

14 276  
15 277 The month-specific estimates of the excess mortality increase gradually throughout the fourth  
16  
17 278 quarter and peak at 7·0 percent (95% CI 4·8 – 8·2 percent) in December 2017 and fluctuate in a  
18  
19 279 downward trajectory during the first quarter of year 2018 (Table 1). These month-specific excess  
20  
21 280 mortality rate estimates imply a pattern of excess death, starting just after the Hurricanes in October  
22  
23 281 2017 with 46 excess deaths (95% CI -12 – 104), up to 160 (95% CI 119 – 201) in December 2017,  
24  
25 282 and 9 (95% CI -19 – 37) in March 2018.

26 283  
27 284 Table 2 reports estimates of excess mortality by age group and gender. Among the population aged  
28  
29 285 65 years or older, mortality was higher than the expected pattern for this population throughout  
30  
31 286 the October 2017-March 2018 period: 7·3 percent (95% CI 0·8 – 13·7 percent) for men and 6·4  
32  
33 287 percent (95% CI 4·1 – 8·8 percent) for women. This is equivalent to 298 excess deaths for men  
34  
35 288 (95% CI 162–366) and the same amount for women (95% CI 250–364). When examining excess  
36  
37 289 mortality by cause of death among this age group, we estimate these to be concentrated in deaths  
38  
39 290 related to heart diseases, cancer, and diabetes; see Supplementary Materials for details.

40 291  
41 292 We find no robust evidence of differences in mortality from the expected pattern for the younger  
42  
43 293 age population throughout this period. The empirical models suggest mortality decreased  
44  
45 294 marginally by 0·5 percent (95% CI -0·5 – 1·6 percent) and 4·1 percent (95% CI 0·4 – 8·6 percent)  
46  
47 295 among, respectively, men and women aged 40-64 years, and by 2·3 percent (95% CI 1·9 – 2·6  
48  
49 296 percent) among men aged 0-39 years.

50 297

---

56 <sup>7</sup> The results are robust to restricting the sample to start in later years (i.e., 2013, 2014), but with somewhat lower levels of precision.  
57  
58  
59

298 **Table 2: Excess Mortality of the Puerto Rican Population in the Mainland U.S., by Age Group and Sex (October 2017 – March 2018)**  
299

	Observed Deaths (1)	Δ Mortality Rate [95% CI] (2)	Population (100,000's) (3)	Expected Deaths (4)	Excess Deaths [95% CI] (5)	Ratio of Observed to Expected Mortality [95% CI] (6)
<b>Panel A: 0-39 Years of Age</b>						
Men	936	-0.023 (-0.026, -0.019)	18.782	957.6	-22 (-23, -20)	0.98 (0.98, 0.98)
Women	433	0.011 (-0.106, 0.129)	17.635	428.2	5 (-18, 28)	1.01 (0.96, 1.07)
<b>Panel B: 40-64 Years of Age</b>						
Men	2,320	-0.005 (-0.016, 0.005)	7.626	2,332.5	-12 (-24, -1)	0.99 (0.99, 1.00)
Women	1,276	-0.041 (-0.086, 0.004)	7.967	1,329.1	-53 (-80, -26)	0.96 (0.94, 0.98)
<b>Panel C: ≥ 65 Years of Age</b>						
Men	4,249	0.073 (0.008, 0.137)	2.222	3,950.9	298 (182, 414)	1.08 (1.04, 1.11)
Women	4,796	0.064 (0.041, 0.088)	3.002	4,498.0	298 (250, 346)	1.07 (1.05, 1.08)
<b>Panel D: All</b>						
Men	7,505	0.036 (0.022, 0.050)	28.630	7,241.0	264 (162, 366)	1.04 (1.02, 1.05)
Women	6,505	0.039 (0.028, 0.050)	28.604	6,255.0	250 (179, 320)	1.04 (1.03, 1.05)

300  
301 Notes: Column 1 reports observed deaths of the Puerto Rican population by gender and age group in the mainland U.S., and column 3 reports estimates of the  
302 overall population of the respective group of Puerto Ricans in the mainland. Column 2 reports estimates of the difference in the natural logarithm of the mortality  
303 of Puerto Ricans relative to Cubans and Mexicans based on the aggregation of OLS estimates from equation 1 estimated for each gender-by-age group, as well as  
304 95 percent confidence intervals in parentheses. Columns 4, 5, and 6 respectively report estimates of expected deaths, excess deaths, and the ratio of observed to  
305 expected deaths calculated from observed deaths (col. 1) and estimates of changes in mortality rates (col. 2); 95 percent confidence intervals of the level of excess  
306 deaths and of the ratio of observed to expected deaths are reported in parentheses.

307 **Table 3: Excess Mortality of the Puerto Rican Population Ages 65 and Older in the Mainland U.S.,**  
 308 **by Education Group and Sex (October 2017 – March 2018)**  
 309

	Observed Deaths (1)	$\Delta$ Mortality Rate [95% CI] (2)	Population (100,000's) (3)	Expected Deaths (4)	Excess Deaths [95% CI] (5)	Ratio of Observed to Expected Mortality [95% CI] (6)
<b>Panel A: 65+ Years of Age, High School Dropouts</b>						
Men	1,802	0.121 (-0.110, 0.352)	0.911	1,597	205 (37, 373)	1.13 (1.01, 1.25)
Women	2,232	0.115 (0.017, 0.214)	1.168	1,989	243 (154, 332)	1.12 (1.07, 1.17)
<b>Panel B: 65+ Years of Age, High School Graduates</b>						
Men	1,560	0.119 (0.044, 0.195)	0.591	1,385	175 (127, 223)	1.13 (1.09, 1.17)
Women	1,565	0.012 (-0.033, 0.058)	0.884	1,546	19 (-13, 51)	1.01 (0.99, 1.03)
<b>Panel C: 65+ Years of Age, Some College or More</b>						
Men	774	0.082 (0.015, 0.150)	0.700	712.8	61 (39, 83)	1.09 (1.05, 1.12)
Women	896	0.121 (0.087, 0.155)	0.929	794.2	102 (89, 114)	1.13 (1.11, 1.15)

310  
 311 Notes: Column 1 reports observed deaths of the Puerto Rican population by gender, age, and education group in the mainland U.S., and column 3 reports estimates  
 312 of the overall population of the respective group of Puerto Ricans in the mainland. Column 2 reports estimates of the difference in the natural logarithm of the  
 313 mortality of Puerto Ricans relative to Cubans and Mexicans based on the aggregation of OLS estimates from equation 1 estimated for each gender-by-age-by-  
 314 education group, as well as 95 percent confidence intervals in parentheses. Columns 4, 5, and 6 respectively report estimates of expected deaths, excess deaths, and  
 315 the ratio of observed to expected deaths calculated from observed deaths (col. 1) and estimates of changes in mortality rates (col. 2); 95 percent confidence intervals  
 316 of the level of excess deaths and of the ratio of observed to expected deaths are reported in parentheses.  
 317

1  
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3 318 The point estimates in Table 3 suggest that populations from all educational levels were affected,  
4  
5 319 but excess deaths were more evident in certain groups. For example, we found 243 excess deaths  
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7 320 (95% CI 154–332) occurred among old age women with less than high school, 175 excess deaths  
8  
9 321 (95% CI 37–373) among old age men with a high school diploma, and 61(95% CI 39-83) and 102  
10  
11 322 (95% CI 89-114) excess deaths among old age men and women respectively with at least some  
12  
13 323 higher education.

14 324

## 15 325 **V. Discussion**

### 16 326 *Main Findings*

17  
18 327 Our study documents an increase in mortality for persons of Puerto Rican origin in the mainland  
19  
20 328 U.S. during the 6-month period following Hurricane Maria (October 2017 through March 2018).  
21  
22 329 Our findings indicate that measures of excess mortality based on death occurrences in Puerto Rico  
23  
24 330 following the Hurricane may be underestimating total excess mortality by an additional 514 deaths  
25  
26 331 (95% CI 346 – 681) in the six months following the event, partly due to significant displacement  
27  
28 332 of the Puerto Rican population to the mainland U.S. Crucially, this increase in mortality was  
29  
30 333 concentrated among the most vulnerable populations, with old age adults with lower levels of  
31  
32 334 education seeing the largest increases. These patterns are consistent with excess mortality  
33  
34 335 estimates obtained in Puerto Rico.<sup>10,11</sup> Analyses of these data also provide a rich description of  
35  
36 336 heterogeneity of the event’s impacts to yield generalizable knowledge.

37 337

### 38 338 *Contribution, Limitations, and Relationship to the Literature*

39  
40 339 The study contributes to the literature documenting the mortality consequences of Hurricane Maria  
41  
42 340 in Puerto Rico. Several previous attempts to estimate the mortality effects of Hurricane Maria in  
43  
44 341 Puerto Rico, including the official death toll estimate prepared by the Government of Puerto Rico,  
45  
46 342 used Puerto Rico death registrar data and previous years’ mortality rate estimates as a benchmark  
47  
48 343 to identify periods of excess mortality in Puerto Rico.<sup>7–11</sup> Preferred mortality estimates for the six  
49  
50 344 and seven-month period following the disaster—which considered only deaths registered in Puerto  
51  
52 345 Rico despite significant population displacement and excluding deaths among the population  
53  
54 346 displaced to the mainland —were as high as 2,975 and 3,400 respectively.<sup>7,10</sup> (We present a  
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56 347 summary of the data, techniques, and treatment periods employed in this research in the Online  
57  
58 348 Supplement.) This focus on deaths occurring in the territory resulted in an underestimation of the

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3 349 death toll by approximately 14.7%, which we estimate occurred in the United States. In contrast,  
4  
5 350 Kishore et al. (2018) surveyed a representative sample of households, asking survivors to account  
6  
7 351 for the whereabouts of all people who lived in their community prior to the Hurricane irrespective  
8  
9 352 of the location of the occurrences of death among community members (on the island or  
10  
11 353 elsewhere). Accordingly, they found a mortality rate that yielded an estimate of 4,645 excess  
12  
13 354 deaths (95% CI 793-8,498) on account of Hurricane Maria. Our finding of excess mortality among  
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15 355 the population of Puerto Rican origin in the mainland U.S. contributes to explaining the difference  
16  
17 356 in estimates from these two methodological approaches.

18  
19 358 An additional contribution of the study is the use of a research design to credibly estimate the  
20  
21 359 excess mortality of displaced and migrant populations during this period while carefully  
22  
23 360 accounting for population displacement following the disaster. Using comparator populations of  
24  
25 361 Cubans and Mexicans in the mainland U.S., our design robustly accounts for different population  
26  
27 362 and mortality trends by age group and gender to account for both displacement and differential  
28  
29 363 mortality among the Puerto Rican population. Our estimates of displacement of the population  
30  
31 364 ages 65 and older of approximately 7.1 percent (40,700 individuals) is in line with the existing  
32  
33 365 literature and supports the consensus using other methodologies that the natural disaster led to  
34  
35 366 displacement in aggregate terms of approximately 4.1-5.6 percent of the total population of Puerto  
36  
37 367 Rico.<sup>17,18</sup> This design, effectively used in related studies and other contexts to account for  
38  
39 368 population movements, is broadly applicable both in other countries and in other disaster contexts  
40  
41 369 (both natural and otherwise), particularly as displacement and mobility becomes an increasingly  
42  
43 370 important feature of natural disasters.<sup>19</sup>

44  
45 372 Our study is informative regarding the broad mortality consequences of the disaster among the  
46  
47 373 displaced and migrant population of Puerto Ricans in the U.S. This measure however limits our  
48  
49 374 ability to quantify the elevated burden of disease from morbidity and disability among this  
50  
51 375 population. We also face some limitations in our ability to precisely estimate cause-specific  
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53 376 mortality or the causal pathways for such trends. Given the relatively small numbers of deaths in  
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55 377 the population in the period under observation (monthly range 2,119–2,862), generating  
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57 378 informative estimates of more finely defined cause-specific mortality is not feasible.

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3 380 Finally, because we use the deaths of persons who are identified as Puerto Rican in their death  
4  
5 381 certificate, our analysis does not allow us to disentangle the excess mortality of displaced  
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7 382 populations as opposed to longer-term migrants or second or third-generation individuals of such  
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9 383 ancestry. Information on the deaths of Puerto Rico residents in the continental U.S. may be  
10  
11 384 incomplete and/or prone to undercounting if the Puerto Rico residency status of such individuals  
12  
13 385 is under-reported on death certificates. This phenomenon is particularly exacerbated among  
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15 386 vulnerable, geographically mobile, migrant populations.<sup>8,9</sup> Nonetheless, the fact our estimated  
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17 387 effects are concentrated among vulnerable populations—consistent with the excess mortality  
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19 388 estimates obtained for death occurrences in Puerto Rico—supports the view that we mainly capture  
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21 389 excess deaths among the sizable population that was displaced to the mainland U.S. following the  
22  
23 390 natural disaster. Future research could undertake epidemiological studies with micro-level data to  
24  
25 391 precisely estimate cause-specific mortality, the causal pathways for such patterns, as well as  
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27 392 mortality estimates that includes all hurricane-related deaths according to CDC guidelines for  
28  
29 393 death occurrences in Puerto Rico and in the continental U.S.

394

### 395 *Policy Implications*

396 Our study emphasizes the importance of considering displaced populations in the calculation of  
397 post-disaster excess mortality. These populations may suffer from relative inattention in the  
398 context of both needs assessment and disaster relief, and we argue that overlooking these provides  
399 an incomplete understanding of the magnitude of the health consequences of natural disasters.

400

401 This analysis suggests the need for not only equitable disaster preparedness, but also the  
402 importance of cross-jurisdiction data sharing.<sup>7</sup> These already vulnerable populations may face a  
403 number of additional hurdles upon relocation, such as healthcare disruptions and psychological  
404 stressors which may exacerbate health impacts of the disaster. Receiving jurisdictions would, thus,  
405 benefit from an improved understanding of both the dynamics of post-disaster displacement and  
406 its consequences.

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<sup>8</sup> Our estimate also excludes persons exposed to the Hurricane, who may have been displaced to other countries, most notably the neighboring Dominican Republic.

<sup>9</sup> While not directly exposed, it is possible that longer-term migrants may have been psychologically or economically affected by the events in the aftermath of Hurricane Maria, which may also have affected their mortality risk. At the same time, this approach excludes from the analysis individuals who are not of Puerto Rican origin but who nevertheless may have been in Puerto Rico at the time of Hurricane, and who may have been displaced in the aftermath of Hurricane Maria.



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5 408 Already important efforts exist among jurisdictions in the U.S., such as the State and Territorial  
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7 409 Exchange of Vital Events (STEVE) of the National Association for Public Health Statistics  
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9 410 Information Systems (NAPHSIS), to facilitate vital records for use by other state-level and  
10  
11 411 territorial public health organizations. However, more coordination is required to speed the flow  
12  
13 412 of data to gain a more comprehensive understanding of the scale of disasters in other countries.  
14  
15 413 Moreover, even among jurisdictions within the U.S., this process can take a considerable amount  
16  
17 414 of time. The speed of flow of vital records depends on the effectiveness of local and county vital  
18  
19 415 registrars to share this information. Ensuring timely exchange of death records among jurisdictions  
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21 416 would ensure disaster death toll estimates based on vital records are complete and would hence  
22  
23 417 allow public authorities to have a comprehensive understanding of the scale of the disaster in a  
24  
25 418 timely fashion.  
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27 419

## 420 **Ethics statements**

### 421 **Patient consent for publication**

422 Not required.

### 423 **Ethics approval**

424 Because these data are publicly available and deidentified, this study is considered to be research  
425 not involving human subjects as defined by U.S. regulation (45 CFR 46.102[d]).

### 426 **Contributorship Statement:**

427 MM: conceptualisation, data curation, supervision, validation, visualisation, writing – original  
428 draft, and writing – review & editing.

429  
430 BM: conceptualisation, data curation, formal analysis, investigation, methodology, visualisation,  
431 writing – original draft, and writing – review & editing.

432  
433 GB: conceptualisation, formal analysis, investigation, methodology, project administration,  
434 supervision, validation, visualisation, writing – original draft, and writing – review & editing.

435  
436 **Competing Interests:** Neither author has any competing interests to declare.

437  
438 **Funding Statement: None**

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3 439  
4 440 **Data Sharing statement**  
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6  
7 441 All data relevant to the study are publicly available (and detailed in the article and supplementary  
8  
9 442 materials).  
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18 449 Figure 1 Caption:  
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21 450 Notes: Standardized monthly mortality from January 2012 to December 2018 (Panel A) and  
22 451 from July 2017 to December 2018 (Panel B). August 2017 is used as the standard mortality rate  
23 452 for both populations.  
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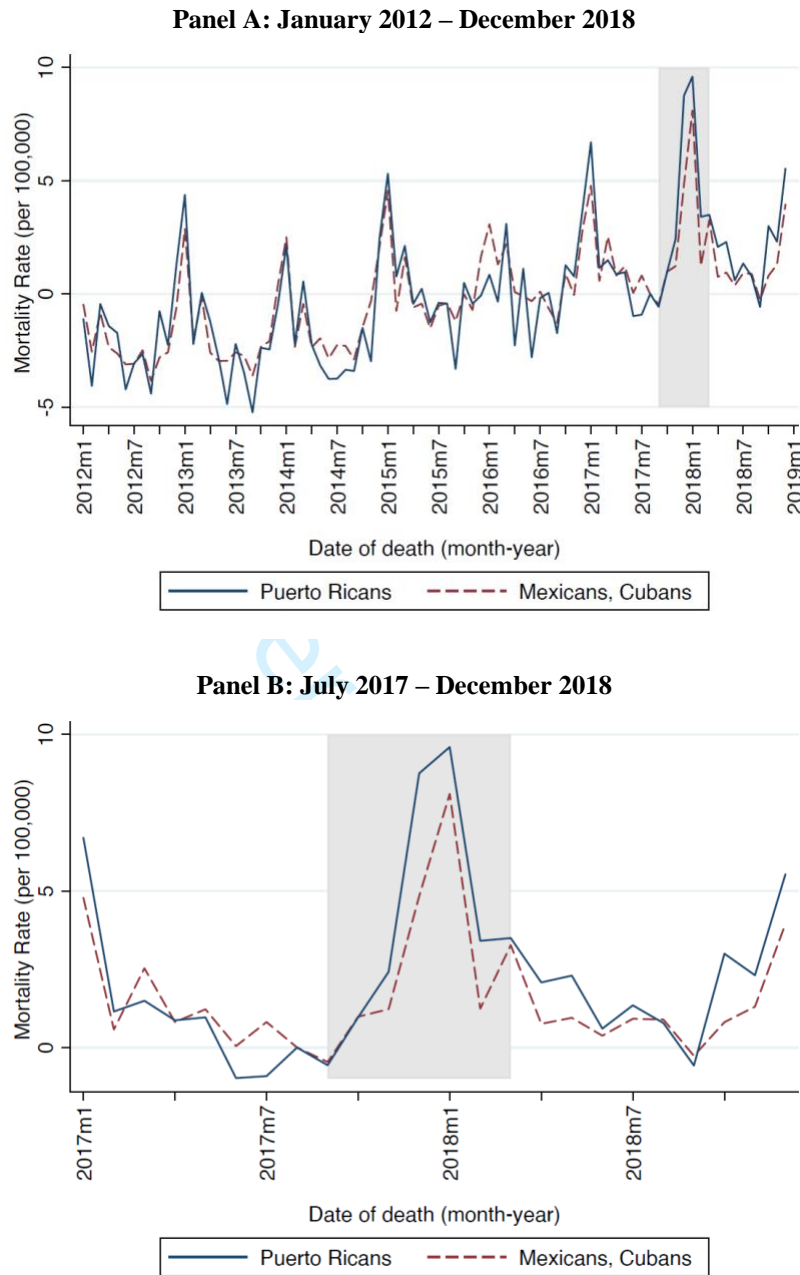
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**Figure 1: Standardized Monthly Mortality Rate of Puerto Ricans vs. Cubans and Mexicans in the US**



Notes: Standardized monthly mortality from January 2012 to December 2018 (Panel A) and from July 2017 to December 2018 (Panel B). August 2017 is used as the standard mortality rate for both populations.

## Supplementary Materials

### A. Additional Figures and Tables

**Table A1. Existing Excess Mortality Estimates of Hurricane Maria<sup>1-5</sup>**

Reference	Main Data Source	Pre-Exposure Period	Exposure Time Period	Estimation Methodology / Design	Preferred Excess Mortality Estimate [95% CI]
Acosta R, Irizarry R. (2018)	Vital records of death occurrences in Puerto Rico	1/1/1985 – 9/20/2017	9/21/2017 – 4/15/2018	Excess mortality	3,400 ± 300
Kishore N. et al. (2018)	Representative, stratified sample household survey	9/20/2016 – 12/31/2016	9/20/2017 – 12/31/2017	Aggregation of mortality reports	4,645 ± 3,852
Santos-Burgoa C. et al. (2018)	Vital records of death occurrences in Puerto Rico	7/1/2010 – 8/31/2017	9/1/2017 – 2/28/2018	Excess mortality	2,975 ± 317
Santos-Lozada A, Howard JT (2018)	Vital records of death occurrences in Puerto Rico	1/1/2010 – 8/31/2017	9/1/2017 – 11/31/2017	Excess mortality	1,139 ± 133
Cruz-Cano R, Mead E (2019)	Vital records of death occurrences in Puerto Rico	1/1/2008 – 8/31/2017	9/1/2017 – 10/31/2017	Excess mortality	1,205 ± 498
Rivera, R., Rolke W. (2019)	Vital records of death occurrences in Puerto Rico	1/1/2015 – 9/19/2017	9/20/2017 – 12/31/2017	Excess mortality	1,318 ± 249

**Notes:** Column 2 reports the main data source used to perform the analysis. Columns 3 and 4 respectively report the period used as a benchmark to identify excess mortality before the Hurricane and the period post-Hurricane during which the period of excess mortality is estimated. Column 5 summarizes the empirical methodology, and column 6 reports the preferred excess mortality estimate and 95% confidence interval.

## B. Methods

### B.1. Temporal Disaggregation of Population Estimates

Annual population estimates of Puerto Ricans, Mexicans and Cubans in the United States were disaggregated to a monthly frequency using the Chow-Lin maxlog method.<sup>6,7</sup> This standard method of temporal disaggregation derives the high-frequency (monthly) data from low frequency (annual) data, allowing for the use of related high-frequency data which the researcher has reason to believe is related to the target time series. In applying this method, the researcher is able to create a high frequency dataset consistent with the initial low-frequency data, but which incorporates the short-term volatility of the related high-frequency data.<sup>1</sup> This is done through a standard least-squares estimation, where the error term is assumed to follow an AR(1) process. In our disaggregation, we chose not to impose a particular short-term volatility, and so regress our low-frequency data for each age-sex-education-Hispanic strata on a constant term, with a mean conversion.

<sup>1</sup> [https://ec.europa.eu/eurostat/cros/content/chow-lin-method-temporal-disaggregation-method\\_en](https://ec.europa.eu/eurostat/cros/content/chow-lin-method-temporal-disaggregation-method_en)

## B.2. Estimation of Excess Mortality Levels – Overall Population and by Subgroup

Our estimation procedure uses the observed age-group-by-gender specific deaths that occurred over the period of October 2018 until March 2018 as well as our estimated coefficients of the differential change in mortality rates of Puerto Ricans in the mainland US ( $\theta_s$  and  $\theta_{st}$ ), to construct estimates of excess mortality for each age-group-gender combination and their corresponding 95 percent confidence interval. To do this:

1. We first obtain the estimates of  $\theta_s$  and  $\theta_{st}$  separately for each age-group-gender combination.
2. We then estimate expected deaths following Maria for each of these subgroups using a non-linear combination of our estimates of the change in mortality rates and the observed deaths. Using nonlinear estimation, we estimate the expected deaths of an age-group-gender combination to be equal to  $\exp(\ln(\text{Observed Deaths}_s) - \theta_s)$ . This is also performed using the period-specific effects ( $\theta_{st}$ ) and observed deaths. This nonlinear estimation procedure also produces standard errors, which are used to construct confidence intervals.
3. We estimate excess deaths by subtracting the expected deaths estimated in (2) from the observed mortality rates for each age-group-gender combination.
4. Finally, to construct the ratio of observed to expected mortality we divide the observed deaths for each age-group-gender combination by our estimate of expected mortality in (2).

To aggregate our age-group-by-gender results to the overall population, we follow a similar procedure:

1. Estimate, as before, our main specification, to obtain a  $\theta_s$  for each of the three age-groups.
2. Aggregate the age group-gender-specific observed deaths to measures at the desired level of aggregation.
3. We then estimate expected deaths following Maria for each of these subgroups using a non-linear combination of our estimates of the change in mortality rates and the observed deaths. Using nonlinear estimation, we calculate, more specifically, the expected deaths of the group,  $h$ , combination to be equal to  $\Sigma_h \exp(\ln(\text{Observed Deaths}_h) - \theta_{sh})$ . This nonlinear estimation procedure also generates standard errors, which are used to construct confidence intervals.
4. Estimate the implied excess deaths by subtracting the expected deaths in (2) from the observed deaths for each age-group:  $\Sigma_h(\text{Observed Deaths}_h) - \Sigma_h \exp(\ln(\text{Observed Deaths}_h) - \theta_{sh})$ .
5. Construct the ratio of observed to expected mortality using the aggregated observed deaths from (2) and the estimated aggregate expected deaths from (3).

## B.3. Estimation of Population Displacement – Overall and by Subgroup

An important consideration in this analysis is our need to estimate the degree of population displacement of the residents of Puerto Rico to the mainland U.S. following the hurricanes. We do so by measuring differential changes in population levels for the Puerto Rican population in the mainland U.S. relative to trends for the comparison groups throughout the period following the Hurricanes.

Again, we make these comparisons by gender and age group, and estimate a system of linear models of the form:

$$\ln(\text{Pop}_{sgmt}) = \tau_s(\text{Maria}_{mt} \times \text{PR}_{sg}) + \mu_{sg} + \delta_{mt} + v_{sgmt}, \quad (\text{B1})$$

where the main outcome and explanatory variables as defined above;  $\mu_{sg}$  are Hispanic group fixed effects;  $\delta_{mt}$  are month-by-year fixed effects; and  $v_{sgmt}$  is the error term; we employ the same estimation procedure. We follow an analogous estimation and aggregation procedure to generate estimates of group-specific and aggregate levels of population displacement in the six-month period following the Hurricane (see Appendix B2 for details). This procedure allows us to both confirm independent estimates of population movements from the territory to the mainland U.S. during this period and to give confidence to the use of population estimates for the estimation of excess mortality rates.

Population displacement was concentrated among the population of individuals ages 65 and older (Table B.1). The population for this group was higher than the expected pattern throughout the October 2017-March 2018 period: the point estimates imply a population increase of 6.0 percent among men (95% CI 1.02 – 1.11) and of 9.7 percent among women (95% CI 1.04 – 1.17) for women. In terms of the temporal pattern, we detect increases in population levels of 2.5 and 14.6 percent among both older age women and men starting in November 2017 until March 2018, with

consistently greater statistical precision among the former group.<sup>2</sup> In contrast, we find no robust evidence of increases in population from the expected pattern for the younger age populations throughout this period. These estimates are consistent with existing evidence that a large share of the post-disaster displacement among the Puerto Rico-based population occurred among the elderly.<sup>2</sup>

**Table A2. Existing Displacement Estimates of Hurricane Maria<sup>8-13</sup>**

Reference	Data source	Treatment Period	Preferred Displacement Estimate
Meléndez and Hinojosa (2017)	American Community Survey	2017-2019	470,335 (14%)
Echenique and Melgar (2018)	Mobile Phone	10/2017 – 02/2018	400,000 (6%)
Alexander, Polimis, and Zagheni (2019)	Facebook, American Community Survey	10/2017 – 01/2018	185,200 (17%)
Santos-Lozada (2019)	Census, Air Travel	2017	154,575
United States Census Bureau (2019)	American Community Survey, Puerto Rico Community Survey	2017 – 2018	142,000 (4.4%)
Acosta et al. (2020)	American/Puerto Rico Community Survey	07/2017-07/2018	129,848 (4%)
	Air Travel	07/2017-07/2018	168,295 (5%)
	Mobile Phone	07/2017-05/2018	235,375 (8%)
	Social Media	08/2017-08/2018	475,779 (17%)

**Notes:** Column 2 reports the main data sources used to estimate displacement effects of Hurricane Maria. The primary treatment period of each paper is indicated in column 3. Column 4 provides the preferred displacement estimate (with the percent change in parentheses).

Table A2 provides a summary of existing displacement estimates from Hurricane Maria. The patterns we document are largely consistent with the remainder of the literature, although with notable exceptions. One reason for these underlying differences is the source(s) of data used in the analysis. For example, Alexander, Polimis and Zagheni (2019), find a 17% increase in the number of Puerto Rican migrants combining Facebook and American Community Survey data. While the magnitude of this estimate is greater than ours, it is consistent with estimates from Acosta et al. (2020) which similarly use social media data and estimate a 17% change in displacement.<sup>3</sup> These social media data have the advantage of providing estimates of population at a time granularity finer than 1-year (as in the case of the ACS and PRCS). One limitation of this type of data, however, is the under-representation or exclusion of older individuals. While Alexander, Polimis and Zagheni (2019) find that changes in population were disproportionately driven by those age 15-30, their analysis does not include individuals over the age of 60. Our estimates suggest that this is an important subpopulation to consider when estimating displacement.

Nevertheless, Acosta et al. (2020) document that using the ACS data generates the smallest estimates of population displacement, with airline passenger and mobile phone data generating larger displacement at a finer time granularity. Finally, data from Facebook shows the largest declines (475,779 – approximately 17%) in population in Puerto Rico

<sup>2</sup> Results available upon request from corresponding author.

<sup>3</sup> These estimates are similar in magnitude to population projections made by Meléndez and Hinojosa (2017), although are substantially larger than estimates using ACS data from the United States Census Bureau (2019), which estimates only 142,000 Puerto Ricans were displaced.



1  
2  
3 following the hurricane. Similar estimates are provided in Echenique and Melgar (2018), who use mobile phone  
4 tracking data to understand population dynamics. While they provide rich information on the destination of these  
5 displaced individuals, little is known about their demographic characteristics.  
6  
7

#### 8 **B.4. Evaluation of Research Design – Placebo Tests of Pre-Event Differential Trends in Mortality**

9 In our interrupted time series / differences-in-differences design, we can test whether there were differences in the  
10 trends in mortality rates between the population of Puerto Rican vs. Mexican/Cuban population prior to the hurricanes  
11 which occurred in September 2017.  
12

13 We implement a series of placebo tests to evaluate whether there are significant increases in mortality of the Puerto  
14 Rican population relative to that of the comparison group. We drop all data from the period September 2017 onwards,  
15 and then create 6-month treatment windows for each period on our sample to mirror our main analysis. We generate  
16 68 placebo differences-in-differences estimates (for event windows starting in January 2012 until August 2018).  
17

18 We compare our true estimate of the change in the mortality rate coefficients  $\theta_s$  to the other placebo estimates obtained,  
19 reporting the percentile rank of the coefficient from the permutation test as well as the approximate p-value. In  
20 addition, we show histograms of the distribution of placebo-based results (see Figure B.1). We conduct this procedure  
21 both for the overall population (Panel A) as well as for individuals ages 65 and older (Panel B).  
22

23 The true estimate of  $\theta_s$  ( $= 0.03732$ ) for the period October 2017 – March 2018 is ranked first in the distribution of  
24 placebo estimates. Specific placebo estimates for the period Oct. 2013-Mar. 2014, Oct. 2014-Mar. 2015, and Oct.  
25 2015-Mar. 2016, and Oct. 2016-Mar. 2017 are  $-0.0117$ ,  $0.0263$ ,  $-0.0113$ , and  $0.0325$ , respectively. For the population  
26 of adults aged 65 and over, the true estimate of  $\theta_s$  ( $= 0.0682$ ) is similarly ranked first in the distribution of placebo  
27 estimates, and the distribution of placebo estimates is centered around zero.<sup>4</sup> Overall, this analysis supports the  
28 assessment that there are common mortality trends across the two groups before the event, and that a significant  
29 deviation takes place in a pronounced manner in the six-month window following these events.  
30

#### 31 **B.5. Estimation of Excess Mortality Levels by Cause of Death**

32 We estimate models of mortality by main cause of death following the hurricanes in order to evaluate possible  
33 pathways connecting the observed excess mortality to the natural disaster. We estimate sets of models as in equation  
34 (1) using the natural logarithm of death counts by category as dependent variables, and follow the same procedure  
35 described in Section B.1 above to generate aggregate estimates of excess mortality by cause of death. We group causes  
36 of death into ten (10) main underlying categories using the NCHS 39-group recode of the ICD 10 Classifications:  
37 heart disease (20-26), cancer (5-15), other diseases (37), external (38-42), liver/kidney related (29-31), respiratory  
38 (27-28), diabetes (16), and Tuberculosis/Syphilis/HIV (1-3). We conduct this analysis both for the overall population  
39 as well as for individuals ages 65 and older (see Table B.2).  
40

41 Excess mortality was concentrated in deaths related to heart disease: the point estimates imply a ratio of observed to  
42 expected deaths of 1.06 among the overall population (95% CI 1.04 – 1.08) and of 1.11 among the adults ages 65  
43 years and older (95% CI 1.07 – 1.14). In overall terms, we also estimate an increase in deaths due to diabetes and  
44 external factors; the ratio of observed to expected deaths are respectively 1.03 (95% CI 1.01 – 1.04) and 1.10 (95%  
45 CI 1.06 – 1.14). Among the old age population, the point estimates of the ratio of observed to expected deaths suggest  
46 increases in cancer (1.05 (95% CI 1.03 – 1.08)), diabetes (1.09 (95% CI 1.08 – 1.09)), and mortality related to other  
47 conditions (1.09 (95% CI 1.05 – 1.13)). Changes in mortality rates related to renal and respiratory conditions are  
48 positive but not significant at conventional confidence levels. These patterns are consistent with the distinct  
49 experiences that are specific to relocation among displaced populations such as additional psychological stressors and  
50 disruption in access to healthcare services as well as changes in their living conditions and social networks.<sup>18,19</sup>  
51  
52  
53  
54

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55 <sup>4</sup> Table 2 reports estimates of 0.073 and 0.064 for men and women ages 65 and over. The estimate for the population ages 65 and  
56 over of both genders is  $\theta_s = 0.0682$ .  
57  
58  
59

**Table B.1:** Estimates of Displacement of Puerto Rican Population to the Mainland US, by Age Group and Sex (October 2017 – March 2018)

	$\Delta \ln(\text{Population})$ [95% CI] (1)	Population (100,000's) (2)	Expected Pop. (3)	Excess Pop [95% CI] (4)	Ratio of Observed to Expected Pop. [95% CI] (5)
<b>Panel A: 0-39 Years of Age</b>					
Men	0.000 (-0.218, 0.218)	18.782	18.783	-0.001 (-1.869, 1.868)	1.00 (0.90, 1.10)
Women	-0.031 (-0.239, 0.178)	17.635	18.189	-0.554 (-2.282, 1.174)	0.97 (0.87, 1.06)
<b>Panel B: 40-64 Years of Age</b>					
Men	0.000 (-0.061, 0.061)	7.626	7.625	0.001 (-0.211, 0.213)	1.00 (0.97, 1.03)
Women	-0.004 (-0.024, 0.016)	7.967	8.000	-0.033 (-0.107, 0.042)	1.00 (0.99, 1.01)
<b>Panel C: <math>\geq 65</math> Years of Age</b>					
Men	0.060 (-0.037, 0.157)	2.222	2.092	0.130 (0.037, 0.222)	1.06 (1.02, 1.11)
Women	0.097 (-0.037, 0.231)	3.002	2.275	0.277 (0.111, 0.443)	1.10 (1.04, 1.17)
<b>Panel D: All</b>					
Men	0.005 (-0.052, 0.061)	28.630	28.500	0.130 (-1.482, 1.742)	1.01 (0.95, 1.06)
Women	-0.011 (-.057, .035)	28.604	28.913	-0.309 (-1.636, 1.017)	0.99 (.94, 1.04)

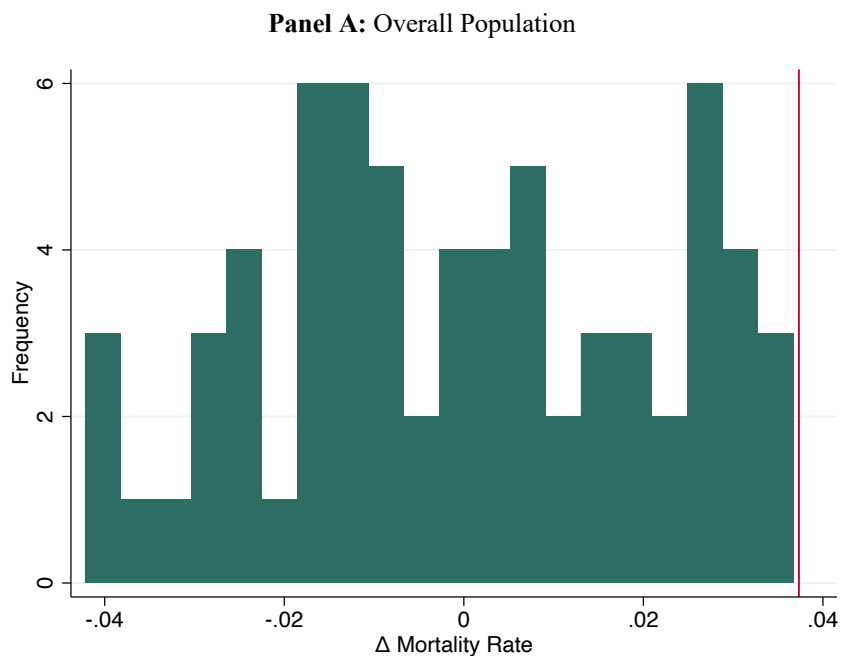
**Notes:** Column 1 reports estimates of the difference in the natural logarithm of the population of Puerto Ricans relative to Cubans and Mexicans in the mainland U.S. based on the aggregation of OLS estimates from equation 1 estimated for each gender-by-age group, as well as 95 percent confidence intervals in parentheses. Column 2 reports estimates of the overall population of Puerto Ricans in the mainland by gender and age group. Columns 3, 4, and 5 respectively report estimates of expected population, excess population (displacement), and the ratio of observed to expected population calculated from the estimated population (col. 2) and estimates of the relative change in population (col. 1); 95 percent confidence intervals of the level of excess population (displacement) and of the ratio of observed to expected population are reported in parentheses.

**Table B.2:** Excess Mortality of the Puerto Rican Population in the Mainland US by Cause of Death, Overall and Old-Age Population (October 2017 – March 2018)

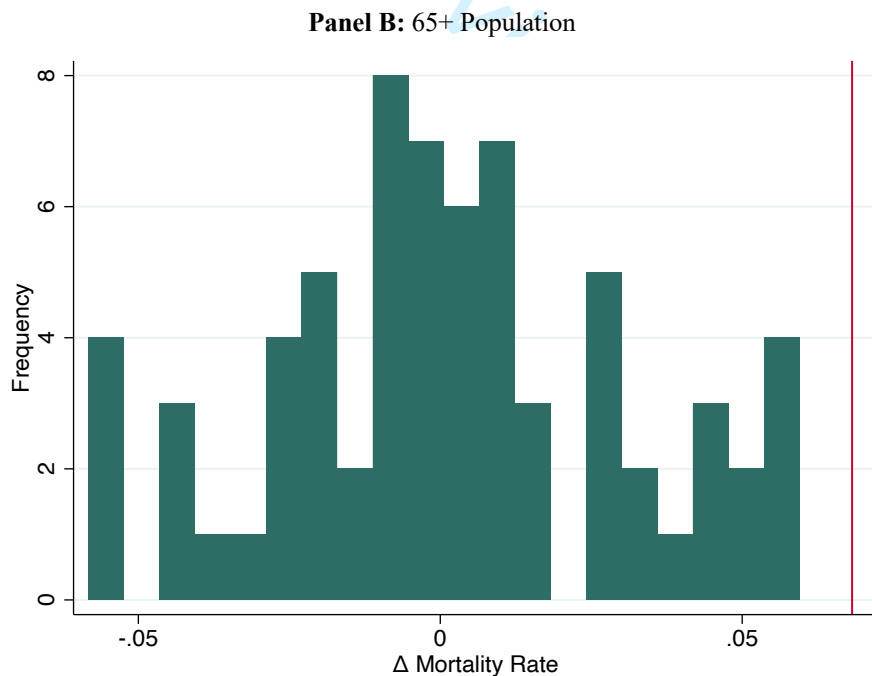
	Observed Deaths (1)	Excess Deaths [95% CI] (2)	Ratio of Observed to Expected Mortality [95% CI] (3)		Observed Deaths (1)	Excess Deaths [95% CI] (2)	Ratio of Observed to Expected Mortality [95% CI] (3)
<b>Panel A: All</b>				<b>Panel B: ≥ 65 Years of Age</b>			
Heart Disease	3,980	223	1.06 (1.04, 1.08)	Heart Disease	3,086	297	1.11 (1.07, 1.14)
Cancer	2,488	29	1.01 (1.00, 1.02)	Cancer	1,624	80	1.05 (1.03, 1.08)
Other	2,577	-1	1.00 (0.94, 1.06)	Other	1,853	154	1.09 (1.05, 1.13)
External	1,627	143	1.10 (1.06, 1.14)	External	282	39	1.21 (1.05, 1.37)
Liver/Kidney	535	-48	0.92 (0.90, 0.94)	Liver/Kidney	301	28	1.10 (0.91, 1.30)
Respiratory	837	15	1.02 (0.84, 1.20)	Respiratory	661	76	1.13 (0.93, 1.33)
Diabetes	601	15	1.03 (1.01, 1.04)	Diabetes	402	32	1.09 (1.08, 1.09)
TB/Syphilis/HIV	118	-1	1.00 (0.92, 1.07)	TB/Syphilis/HIV	49	6	1.14 (1.13, 1.15)

**Notes:** Column 1 reports observed mortality by cause of death of the Puerto Rican population, overall (left panel) and for those 65 years and older (right panel), in the mainland U.S. Columns 2 and 3 respectively report estimates of excess deaths and the ratio of observed to expected deaths calculated from observed deaths (col. 1) and estimates of changes in mortality rates by cause of death based on equation 1; 95 percent confidence intervals of the level of the ratio of observed to expected deaths are reported in parentheses.

**Figure B.1:** Distribution of Placebo Tests for Evaluation of Differences-in-Differences Research Design



Notes: Distribution of placebo effects on the change in the natural logarithm of deaths among Puerto Ricans relative to Cubans and Mexicans in the mainland U.S. (comparable to true estimate in Table 1, Panel B:  $\theta_s = 0.03732$  indicated by the red vertical line).



Notes: Distribution of placebo effects on the change in the natural logarithm of deaths among Puerto Ricans relative to Cubans and Mexicans in the mainland U.S. age 65+ (comparable to true estimate  $\theta_s = 0.0682$  indicated by the red vertical line).

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60STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

	<b>Item No</b>	<b>Recommendation</b>	
<b>Title and abstract</b>	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	Page 1, Title
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	Page 1, Summary
<b>Introduction</b>			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Page 2, Paragraph 1-3
Objectives	3	State specific objectives, including any prespecified hypotheses	Page 2, Paragraph 4
<b>Methods</b>			
Study design	4	Present key elements of study design early in the paper	Page 3, Paragraph 1
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Page 1, Summary
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants	Page 3, Section II, Paragraph 1
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Page 3, Section II, Paragraph 1-2
Data sources/measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Page 3, Section II, Paragraph 1-2
Bias	9	Describe any efforts to address potential sources of bias	Page 4 paragraph 2-3, page 5 paragraph 1
Study size	10	Explain how the study size was arrived at	n/a
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Page 3, Section II, Paragraph 2
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	Page 4, Section III
		(b) Describe any methods used to examine subgroups and interactions	Page 4, Section III, Paragraph 1
		(c) Explain how missing data were addressed	Page 3, Section II, Paragraph 3
		(d) If applicable, describe analytical methods taking account of sampling strategy	N/A
		(e) Describe any sensitivity analyses	N/A
<b>Results</b>			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the	Page 5, Section IV, Paragraph 1

		study, completing follow-up, and analysed	
		(b) Give reasons for non-participation at each stage	n/a
		(c) Consider use of a flow diagram	n/a
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Page 5, Section IV, Paragraph 1
		(b) Indicate number of participants with missing data for each variable of interest	N/A
Outcome data	15*	Report numbers of outcome events or summary measures	Page 5, Section IV, Paragraph 1
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Page 5, Section IV
		(b) Report category boundaries when continuous variables were categorized	Page 3, Section II, paragraph 5
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Page 4 paragraph 6
<b>Discussion</b>			
Key results	18	Summarise key results with reference to study objectives	Page 6, paragraph 3
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Page 6, paragraph 4
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Page 6
Generalisability	21	Discuss the generalisability (external validity) of the study results	Page 6, paragraph 2
<b>Other information</b>			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	N/A

\*Give information separately for exposed and unexposed groups.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at [www.strobe-statement.org](http://www.strobe-statement.org).

# BMJ Open

## Mortality of Puerto Ricans in the United States Post-Hurricane Maria: An Interrupted Time Series Analysis

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3 **1 Mortality of Puerto Ricans in the United States Post-Hurricane Maria: An Interrupted Time**  
4 **2 Series Analysis**  
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3 40 **Mortality of Puerto Ricans in the United States Post-Hurricane Maria: An Interrupted Time**  
4 41 **Series Analysis**  
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6 42

7 43 ***Abstract***

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9 44 *Objectives:* To determine death occurrences of Puerto Ricans on the mainland U.S. following the  
10 45 arrival of Hurricane Maria in Puerto Rico in September 2017.

11  
12 46 *Design:* Cross-sectional study

13  
14 47 *Participants:* Persons of Puerto Rican origin on the mainland United States

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16 48 *Exposures:* Hurricane Maria

17  
18 49 *Main Outcome:* We use an interrupted time-series design to analyze all-cause mortality of Puerto  
19 50 Ricans in the U.S. following the Hurricane. Hispanic Origin data from the National Vital Statistics  
20 51 System and from the Public Use Microdata Sample of the American Community Survey are used  
21 52 to estimate monthly origin-specific mortality rates for the period 2012 to 2018. We estimated log-  
22 53 linear regressions of monthly deaths of persons of Puerto Rican origin by age group, gender, and  
23 54 educational attainment.

24  
25 55 *Results:* We found an increase in mortality for persons of Puerto Rican origin during the 6-month  
26 56 period following the Hurricane (October 2017 through March 2018), suggesting that deaths among  
27 57 these persons were 3·7% (95% CI: 0·025-0·049) higher than would have otherwise been expected.  
28 58 In absolute terms, we estimated 514 excess deaths (95% CI 346 – 681) of persons of Puerto Rican  
29 59 origin that occurred on the mainland U.S., concentrated in those aged 65 years or older.

30  
31 60 *Conclusions:* Our findings suggest an undercounting of previous deaths as a result of the hurricane  
32 61 due to the systematic effects on the displaced and resident population in the mainland U.S.  
33 62 Displaced populations are frequently overlooked in disaster relief and subsequent research.  
34 63 Ignoring these populations provides an incomplete understanding of the damages and loss of life.  
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3 764  
5 776 78 *Article Summary*7  
8 79 *Strengths and limitations*

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- 10 80 • One of the first studies to examine excess mortality among migrant and displaced
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- 11 81 populations following a natural disaster.
- 
- 12 82 • Leverage comparison group mortality outcomes to control for seasonality and period-
- 
- 13 83 specific effects, minimizing potential confounding.
- 
- 14 84 • As the mortality outcomes are aggregated at the Hispanic group and gender-age group
- 
- 15 85 stratum in each month, we are unable to precisely measure cause-specific mortality.
- 
- 16 86 • Our analysis does not allow us to disentangle the excess mortality of displaced populations
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- 17 87 as opposed to longer-term migrants or second or third-generation individuals of such
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- 18 88 ancestry.
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## 1. Introduction

Extreme weather events such as hurricanes are growing in frequency and magnitude and are expected to affect a growing population due to migration patterns, ecosystem alteration, and climate.<sup>1,2</sup> The consequences for human lives and the economic costs associated with these disasters are high.<sup>3,4</sup> While much research documents the direct impacts of natural disasters on the mortality, morbidity, and socioeconomic consequences of populations in affected areas, substantially less attention has been paid to the consequences for populations displaced as a result of these events.<sup>3,5,6</sup>

While all victims of natural disasters face common challenges, displaced populations undergo distinct experiences that are specific to their relocation—such as additional psychological stressors and disruption in access to healthcare services as well as changes in their living conditions and social networks.<sup>1</sup> These circumstances can either compound or mitigate the effects of disasters for these populations. Consistent with the heterogeneity in the populations' experiences, a growing body of research finds mixed evidence regarding the incidence and extent of higher mortality risk among displaced populations.<sup>2</sup>

However, measuring the mortality consequences of disasters among these populations is inherently challenging due to the displacement that can take place before, during or in the aftermath of an event.<sup>3</sup> Few studies of displaced populations have analyzed representative sample data before and after exposure to a disaster relative to comparable populations to be able to credibly measure the effects of these events.<sup>4</sup> In spite of these methodological limitations, this literature has shaped our understanding of mortality patterns among displaced populations. If conclusions about these forms

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<sup>1</sup> See Uscher-Pines and Frankenberg, Laurito, and Thomas for systematic reviews of the literatures on the health effects of relocation following disaster and of the demographic consequences of disasters more generally.<sup>7,8</sup>

<sup>2</sup> In an early systematic review of the literature, Uscher-Pines documents no short nor long-term consequences on mortality for displaced populations following post-disaster relocation.<sup>8</sup> Subsequent studies find higher mortality risks for specific displaced subpopulations such as among relocated institutionalized elderly; see Willoughby et al. for a systematic review.<sup>9</sup>

<sup>3</sup> Most data on disasters are obtained from those who remain relatively near the site of the disaster or who have relocated to obvious camps and refugee settlements. The mortality of the rest of the displaced population may be missed if proper attention is not taken in the design of data collection efforts. Furthermore, displacement makes it difficult to know how completely those interviewed represent the underlying population exposed to the event, nor is it possible to benchmark respondents' experiences during and after an event against their circumstances before the event, or against populations that were not exposed to the event but are otherwise similar.<sup>6,10</sup>

<sup>4</sup> Specifically, studies of populations after large-scale disasters typically describe the experiences of particular groups of individuals—such as those displaced to specialized refugee locations—providing little information about individuals who settled elsewhere, although there are exceptions.<sup>6,7,10–16</sup>

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3 114 of vulnerability do not transcend specific groups and cannot be replicated more generally, their  
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5 115 informativeness in planning for or responding to the needs of at-risk populations—monitoring,  
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7 116 assessment, programming of interventions and the targeting of social safety nets—is compromised.  
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10 118 In this article, we contribute to research on the mortality consequences of extreme environmental  
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12 119 hazards among displaced populations in host communities.<sup>5</sup> Our objective is to estimate the excess  
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14 120 mortality experienced by Puerto Ricans in the mainland U.S. following the devastation caused in  
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16 121 Puerto Rico by Hurricanes Irma and Maria in September 2017. The consensus from existing  
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18 122 research documenting excess mortality in the aftermath of the Hurricanes—based on death  
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20 123 occurrences that happened physically in the archipelago of Puerto Rico—is that well over one  
21  
22 124 thousand people died in Puerto Rico and likely more than three thousand lost their lives (see  
23  
24 125 Supplementary Materials Table A1).<sup>17–21</sup> However, to date, no systematic attempt had been made  
25  
26 126 to consider deaths that may have occurred on the mainland United States as a result of this natural  
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28 127 disaster. To our knowledge, this is the first study to explicitly examine the post-disaster death  
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30 128 occurrences of Puerto Ricans in the mainland U.S.

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32 130 We combine administrative death records data from the U.S. National Vital Statistics System  
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34 131 together with population estimates using repeated cross-sections of the Public Use Microdata  
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36 132 Sample of the American Community Survey to estimate monthly immigrant-origin group-specific  
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38 133 mortality rates by age, gender, and educational attainment for the period 2012 to 2018 in the  
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40 134 mainland U.S. Using these data, which is representative of the at-risk population, we conduct  
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42 135 analyses that measure outcomes consistently for individuals from the group affected by the disaster  
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44 136 relative to those of comparable populations. We use an interrupted time-series differences-in-  
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46 137 differences design to examine patterns of all-cause mortality of Puerto Ricans in the United States  
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48 138 during the months following the Hurricane, using mortality trends for Cuban and Mexican  
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50 139 populations in the mainland U.S.—whose countries of origin or ancestry were not affected by  
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52 140 extreme hurricanes that year (or limited population displacement to the U.S. as a result of these  
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54 141 events) and who had historically similar mortality trends preceding the event—as a comparison  
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56 142 group.

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<sup>5</sup> We conceptualize post-disaster mobility as a coping strategy that occurs along a spectrum from forced displacement to largely voluntary migration.<sup>6,22–24</sup>

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5 144 Identifying the existence and magnitude of a period of excess mortality among Puerto Ricans in  
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7 145 the United States in the months following the passage of Hurricane Maria over Puerto Rico would  
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9 146 support the hypothesis that displaced and migrant populations also face a higher risk of mortality  
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11 147 and possibly other health consequences from exposure to such natural disasters.  
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## 13 149 **2. Methods**

### 14 150 **2.1 Data and Descriptive Statistics**

15 151 We use publicly available microdata from the National Vital Statistics System of the National  
16  
17 152 Center for Health Statistics to identify deaths of persons of Puerto Rican origin on the mainland  
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19 153 United States between 2012 and 2018.<sup>25</sup> The data also allows us to identify deaths of persons of  
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21 154 other Hispanic origins, which we use as a comparison group. It also includes the month of  
22  
23 155 occurrence, as well as several socio-economic variables for each death, including the person's age,  
24  
25 156 gender, and educational attainment.  
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28  
29 158 We use the Public Use Microdata Sample of the American Community Survey (ACS) of the U.S.  
30  
31 159 Census Bureau to estimate the annual population of each Hispanic origin, for each age group,  
32  
33 160 gender, and educational attainment between 2012 and 2018.<sup>26</sup> Following Santos Burgoa et al.  
34  
35 161 (2018), age was categorized in three groups: 0-39 years, 40-64 years, and 65 years or older. For  
36  
37 162 age groups 40-64 years and 65 years and older, we also stratified the sample in three groups based  
38  
39 163 on individuals' educational attainment: persons who did not complete high school, those with only  
40  
41 164 a high school degree, and those with some higher education or more.  
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44 166 We employ a standard temporal disaggregation method for time series data based on dynamic  
45  
46 167 models to generate stratum-specific population measures for each month.<sup>27,28</sup> The technique  
47  
48 168 exploits the time-series relationship of the available low-frequency data using a regression model  
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50 169 with autocorrelated errors generated by a first-order autoregressive process. The reference period  
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52 170 of the ACS is the 12-month calendar year. As a result, we also restrict the 12-month average  
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54 171 population estimate to equal the annual ACS-based population estimate; see Supplementary  
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56 172 Materials for details.  
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3 174 Because these data are publicly available and deidentified, this study is considered to be research  
4  
5 175 not involving human subjects as defined by U.S. regulation (45 CFR 46.102[d]).  
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## 8 177 **2.2 Patient and Public Involvement**

9  
10 178 No patients involved.  
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12 179

## 13 180 **2.3 Statistical Analysis**

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15 181 Our empirical strategy consists of an interrupted time series / difference-in-differences design. We  
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17 182 compare differences in the gender-by-age group stratum mortality rates of Puerto Ricans before  
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19 183 and after September 2017 relative to that of Cubans and Mexicans, comparable Hispanic groups  
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21 184 in the U.S., during the January 2012-December 2018 time period. In doing so, we effectively use  
22  
23 185 the mortality outcomes of the comparison groups to control for seasonality and period-specific  
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25 186 effects. We make these comparisons by gender-by-age group, estimating a system of six (6) linear  
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27 187 models of the form:  
28

$$29 \quad 189 \quad \ln(d_{sgmt}) = \theta_s(\text{Maria}_{mt} \times \text{PR}_{sg}) + \beta_s \ln(\text{Pop}_{sgmt}) + \alpha_{sg} + \gamma_{mt} + \varepsilon_{sgmt}, \quad (1)$$

30  
31 190  
32  
33 191 where  $d_{sgmt}$  is the number of deaths of individuals from gender-age group stratum  $s$  and Hispanic  
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35 192 group  $g$  in month  $m$  and year  $t$ ;  $\text{Maria}_{mt}$  is an indicator variable for the 6-month period from October  
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37 193 2017 to the March 2018;  $\text{PR}_{sg}$  is an indicator variable for Puerto Rican origin;  $\text{Pop}_{sgmt}$  is the  
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39 194 population level estimate for each Hispanic group  $g$  over time;  $\alpha_{sg}$  are Hispanic group fixed effects;  
40  
41 195  $\gamma_{mt}$  are month-by-year fixed effects; and  $\varepsilon_{sgmt}$  is the error term. This model richly captures  
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43 196 seasonality as well as other time trends for each gender-by-age stratum, and accounts for  
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45 197 differences in the mortality rate levels between Puerto Ricans and other Hispanic groups. We  
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47 198 estimate the models as a system of equations allowing for autocorrelation of the error terms by  
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49 199 clustering standard errors at the Hispanic group level.<sup>29–31</sup> This procedure also allows us to account  
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51 200 for the correlation of mortality rates across age groups and gender within each Hispanic group as  
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53 201 well as the autocorrelation of mortality for each group, and to generate estimates of aggregate  
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55 202 excess mortality for the population based on the stratum-specific models.  
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3 204 We also report a series of estimates from an event study to document the month-specific effects of  
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5 205 the Maria shock. Specifically, we estimate equation (2) to explore this:  
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$$8 \quad 207 \quad \ln(d_{sgmt}) = \theta_{st} \cdot \mathbf{I}\{g = \text{PR}_g\} \cdot \mathbf{I}\{t = 1, 2, \dots, 6\} + \beta_s \ln(\text{Pop}_{sgmt}) + \alpha_{sg} + \gamma_{mt} + \varepsilon_{sgmt}, \quad (2)$$

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11 209 where  $\mathbf{I}\{g = \text{PR}_g\} \cdot \mathbf{I}\{t = 1, 2, \dots, 6\}$  is a vector capturing the interaction of the PR indicator with an  
12 210 indicator variable for each month from October 2017 to March 2018, with September 2017 – the  
13  
14 211 month of the event – as the base period. All other variables are as defined above in equation (1).  
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16 212 The vector  $\theta_{st}$  captures the period-specific effects for each month during the 6-month window  
17  
18 213 described earlier.  
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22 215 Our estimation procedure uses the observed age-group-by-gender specific deaths that occurred  
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24 216 over the period of October 2017 until March 2018 as well as our estimated coefficients of the  
25  
26 217 differential change in mortality rates of Puerto Ricans in the mainland U.S. ( $\theta_s, \theta_{st}$ ), to construct  
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28 218 estimates of excess mortality for each age-group-sex combination and their corresponding 95  
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30 219 percent confidence interval. We follow an analogous procedure to generate estimates of excess  
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32 220 mortality for the population in overall terms. See Supplementary Materials for details of the  
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34 221 estimation and aggregation procedures.  
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36 222

37 223 An important consideration in this analysis is our need to estimate the degree of population  
38 224 displacement of the residents of Puerto Rico to the mainland U.S. following the hurricanes. We do  
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40 225 so by measuring differential changes in population levels for the Puerto Rican population in the  
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42 226 mainland U.S. relative to trends for the comparison groups throughout the period following the  
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44 227 Hurricanes. This methodology, described in more detail the Supplementary Materials, generates  
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46 228 estimates of population displacement, or the population in excess of what would have otherwise  
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48 229 been expected. This procedure allows us to both confirm independent estimates of population  
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50 230 movements from the territory to the mainland U.S. during this period and to give confidence to the  
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52 231 use of population estimates for the estimation of excess mortality rates.  
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#### 53 233 **IV. Results**

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3 234 14,010 individuals of Puerto Rican background died in the mainland U.S. between October 2017  
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5 235 and March 2018 (Table 1); 7,505 (53.6%) were men and 6,505 (46.4%) were women (Table 2);  
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7 236 9,045 (64.6%) were adults aged 65 years or older (Table 3). In contrast, between 10,866 and 12,832  
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9 237 deaths occurred among this population in the six-month period between October and March in the  
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11 238 2012-13 to 2016-17 years, the period of observation before the hurricane. We estimated that there  
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13 239 were approximately 5.631 million individuals of Puerto Rican origin in the mainland U.S. in  
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15 240 August 2017, and by March 2018, this number was 5.783 million—an increase of approximately  
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17 241 152,000 individuals, or a 2.7 percent population increase (Table 1).  
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20  
21 243 We compare mortality outcomes pre and post September 2017 among the Puerto Rican population  
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23 244 in the mainland U.S. relative to other Hispanic groups in the country. In Panel A of Figure 1 we  
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25 245 examine trends in the overall mortality rate of Puerto Ricans in the mainland U.S. (blue solid line)  
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27 246 during January 2012-December 2018 and that of Cubans and Mexicans (red dashed line)  
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29 247 throughout the same period. Between January of 2012 and August 2017, the mortality rate among  
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31 248 individuals of Puerto Rican origin averaged 280.89 per 100,000. In contrast, the mortality rate  
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33 249 among Cubans and Mexicans throughout this period was 232.17 per 100,000. In spite of this  
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35 250 difference in mortality levels, the two groups experienced very similar mortality seasonal patterns  
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37 251 and trends in the period up to September 2017, when Puerto Rico was severely affected by  
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39 252 Hurricanes Irma and Maria (Figure 1, Panel A).  
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42  
43 254 Following these events, we observe a modest trend break in the mortality rate of Puerto Ricans  
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45 255 relative to that of Cubans and Mexicans, in the 0.08-4.03 deaths per 100,000 range (Figure 1,  
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47 256 Panel B). The figure helps validate the research design.<sup>6</sup> Moreover, it reveals the mortality rate  
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49 257 gap to be most pronounced during the October 2017 through March 2018; we use this post-  
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51 258 Hurricane six-month event window to capture estimates of excess mortality for the Puerto Rican  
52  
53 259 population in the mainland U.S.

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55 <sup>6</sup> In the Supplemental Appendix, we include a series of placebo tests we performed to evaluate whether there are significant  
56 increases in mortality of the Puerto Rican population relative to that of the comparison group pre-October 2017, which confirm the  
57 common trends assumption.

**Table 1: Excess Mortality of the Puerto Rican Population in the Mainland U.S., Overall and by Month (October 2017 – March 2018)**

	Observed Deaths (1)	$\Delta$ Mortality Rate [95% CI] (2)	Population (100,000's) (3)	Expected Deaths (4)	Excess Deaths [95% CI] (5)	Ratio of Observed to Expected Mortality [95% CI] (6)
<b>Panel A: Month-Specific Estimates</b>						
October 2017	2,093	0.022 (-0.006, 0.051)	56.596	2,047	46 (-11.7, 104.1)	1.02 (0.99, 1.05)
November 2017	2,182	0.059 (0.041, 0.078)	56.767	2,056	126 (87.1, 164.7)	1.06 (1.04, 1.08)
December 2017	2,551	0.065 (0.048, 0.082)	56.974	2,391	160 (119.4, 200.7)	1.07 (1.05, 1.09)
January 2018	2,624	0.012 (-0.014, 0.039)	57.524	2,592	32 (-36.1, 100.5)	1.01 (0.99, 1.04)
February 2018	2,275	0.059 (0.035, 0.083)	57.708	2,145	130 (78.1, 182.4)	1.06 (1.03, 1.09)
March 2018	2,285	0.004 (-0.008, 0.016)	57.830	2,276	9 (-19.1, 36.8)	1.00 (0.99, 1.02)
<b>Panel B: Aggregate Estimates</b>						
October 2017 - March 2018	14,010	0.037 (0.025, 0.050)	57.233	13,496	514 (346.5, 681.0)	1.04 (1.03, 1.05)
October 2017 - December 2017	6,826	0.037 (0.024, 0.049)	56.779	6,581	245 (163.6, 326.9)	1.04 (1.02, 1.05)

Notes: Column 1 reports observed deaths of the Puerto Rican population in the mainland U.S., and column 3 reports estimates of the overall population of Puerto Ricans in the mainland. Column 2 reports estimates of the difference in the natural logarithm of the mortality of Puerto Ricans relative to Cubans and Mexicans based on the aggregation of OLS estimates from equation 2 (Panel A) and equation 1 (Panel B) estimated for each gender-by-age group, as well as 95 percent confidence intervals in parentheses. Columns 4, 5, and 6 respectively report estimates of expected deaths, excess deaths, and the ratio of observed to expected deaths calculated from observed deaths (col. 1) and estimates of changes in mortality rates (col. 2); 95 percent confidence intervals of the level of excess deaths and of the ratio of observed to expected deaths are reported in parentheses.

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3 270 Our results span the six-month period following the passing of Hurricane Maria (October 2017 –  
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5 271 March 2018). We find a statistically significant increase in the mortality rate for persons of Puerto  
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7 272 Rican origin during this period of approximately 3·7 percent (95% CI 2·4 – 4·9 percent) higher  
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9 273 than would have otherwise been expected (see Table 1).<sup>7</sup> In absolute terms, this is equivalent to  
10  
11 274 514 excess deaths (95% CI 346 – 681) of persons of Puerto Rican origin that occurred on the  
12  
13 275 mainland United States.

14 276  
15 277 The month-specific estimates of the excess mortality increase gradually throughout the fourth  
16  
17 278 quarter and peak at 7·0 percent (95% CI 4·8 – 8·2 percent) in December 2017 and fluctuate in a  
18  
19 279 downward trajectory during the first quarter of year 2018 (Table 1). These month-specific excess  
20  
21 280 mortality rate estimates imply a pattern of excess death, starting just after the Hurricanes in October  
22  
23 281 2017 with 46 excess deaths (95% CI -12 – 104), up to 160 (95% CI 119 – 201) in December 2017,  
24  
25 282 and 9 (95% CI -19 – 37) in March 2018.

26 283  
27 284 Table 2 reports estimates of excess mortality by age group and gender. Among the population aged  
28  
29 285 65 years or older, mortality was higher than the expected pattern for this population throughout  
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31 286 the October 2017-March 2018 period: 7·3 percent (95% CI 0·8 – 13·7 percent) for men and 6·4  
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33 287 percent (95% CI 4·1 – 8·8 percent) for women. This is equivalent to 298 excess deaths for men  
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35 288 (95% CI 162–366) and the same amount for women (95% CI 250–364). When examining excess  
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37 289 mortality by cause of death among this age group, we estimate these to be concentrated in deaths  
38  
39 290 related to heart diseases, cancer, and diabetes; see Supplementary Materials for details.

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41 292 We find no robust evidence of differences in mortality from the expected pattern for the younger  
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43 293 age population throughout this period. The empirical models suggest mortality decreased  
44  
45 294 marginally by 0·5 percent (95% CI -0·5 – 1·6 percent) and 4·1 percent (95% CI 0·4 – 8·6 percent)  
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47 295 among, respectively, men and women aged 40-64 years, and by 2·3 percent (95% CI 1·9 – 2·6  
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49 296 percent) among men aged 0-39 years.

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56 <sup>7</sup> The results are robust to restricting the sample to start in later years (i.e., 2013, 2014), but with somewhat lower levels of precision.  
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59

298 **Table 2: Excess Mortality of the Puerto Rican Population in the Mainland U.S., by Age Group and Sex (October 2017 – March 2018)**  
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	Observed Deaths (1)	Δ Mortality Rate [95% CI] (2)	Population (100,000's) (3)	Expected Deaths (4)	Excess Deaths [95% CI] (5)	Ratio of Observed to Expected Mortality [95% CI] (6)
<b>Panel A: 0-39 Years of Age</b>						
Men	936	-0.023 (-0.026, -0.019)	18.782	957.6	-22 (-23, -20)	0.98 (0.98, 0.98)
Women	433	0.011 (-0.106, 0.129)	17.635	428.2	5 (-18, 28)	1.01 (0.96, 1.07)
<b>Panel B: 40-64 Years of Age</b>						
Men	2,320	-0.005 (-0.016, 0.005)	7.626	2,332.5	-12 (-24, -1)	0.99 (0.99, 1.00)
Women	1,276	-0.041 (-0.086, 0.004)	7.967	1,329.1	-53 (-80, -26)	0.96 (0.94, 0.98)
<b>Panel C: ≥ 65 Years of Age</b>						
Men	4,249	0.073 (0.008, 0.137)	2.222	3,950.9	298 (182, 414)	1.08 (1.04, 1.11)
Women	4,796	0.064 (0.041, 0.088)	3.002	4,498.0	298 (250, 346)	1.07 (1.05, 1.08)
<b>Panel D: All</b>						
Men	7,505	0.036 (0.022, 0.050)	28.630	7,241.0	264 (162, 366)	1.04 (1.02, 1.05)
Women	6,505	0.039 (0.028, 0.050)	28.604	6,255.0	250 (179, 320)	1.04 (1.03, 1.05)

300  
301 Notes: Column 1 reports observed deaths of the Puerto Rican population by gender and age group in the mainland U.S., and column 3 reports estimates of the  
302 overall population of the respective group of Puerto Ricans in the mainland. Column 2 reports estimates of the difference in the natural logarithm of the mortality  
303 of Puerto Ricans relative to Cubans and Mexicans based on the aggregation of OLS estimates from equation 1 estimated for each gender-by-age group, as well as  
304 95 percent confidence intervals in parentheses. Columns 4, 5, and 6 respectively report estimates of expected deaths, excess deaths, and the ratio of observed to  
305 expected deaths calculated from observed deaths (col. 1) and estimates of changes in mortality rates (col. 2); 95 percent confidence intervals of the level of excess  
306 deaths and of the ratio of observed to expected deaths are reported in parentheses.

307 **Table 3: Excess Mortality of the Puerto Rican Population Ages 65 and Older in the Mainland U.S.,**  
 308 **by Education Group and Sex (October 2017 – March 2018)**  
 309

	Observed Deaths (1)	$\Delta$ Mortality Rate [95% CI] (2)	Population (100,000's) (3)	Expected Deaths (4)	Excess Deaths [95% CI] (5)	Ratio of Observed to Expected Mortality [95% CI] (6)
<b>Panel A: 65+ Years of Age, High School Dropouts</b>						
Men	1,802	0.121 (-0.110, 0.352)	0.911	1,597	205 (37, 373)	1.13 (1.01, 1.25)
Women	2,232	0.115 (0.017, 0.214)	1.168	1,989	243 (154, 332)	1.12 (1.07, 1.17)
<b>Panel B: 65+ Years of Age, High School Graduates</b>						
Men	1,560	0.119 (0.044, 0.195)	0.591	1,385	175 (127, 223)	1.13 (1.09, 1.17)
Women	1,565	0.012 (-0.033, 0.058)	0.884	1,546	19 (-13, 51)	1.01 (0.99, 1.03)
<b>Panel C: 65+ Years of Age, Some College or More</b>						
Men	774	0.082 (0.015, 0.150)	0.700	712.8	61 (39, 83)	1.09 (1.05, 1.12)
Women	896	0.121 (0.087, 0.155)	0.929	794.2	102 (89, 114)	1.13 (1.11, 1.15)

310  
 311 Notes: Column 1 reports observed deaths of the Puerto Rican population by gender, age, and education group in the mainland U.S., and column 3 reports estimates  
 312 of the overall population of the respective group of Puerto Ricans in the mainland. Column 2 reports estimates of the difference in the natural logarithm of the  
 313 mortality of Puerto Ricans relative to Cubans and Mexicans based on the aggregation of OLS estimates from equation 1 estimated for each gender-by-age-by-  
 314 education group, as well as 95 percent confidence intervals in parentheses. Columns 4, 5, and 6 respectively report estimates of expected deaths, excess deaths, and  
 315 the ratio of observed to expected deaths calculated from observed deaths (col. 1) and estimates of changes in mortality rates (col. 2); 95 percent confidence intervals  
 316 of the level of excess deaths and of the ratio of observed to expected deaths are reported in parentheses.  
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3 318 The point estimates in Table 3 suggest that populations from all educational levels were affected,  
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5 319 but excess deaths were more evident in certain groups. For example, we found 243 excess deaths  
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7 320 (95% CI 154–332) occurred among old age women with less than high school, 175 excess deaths  
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9 321 (95% CI 37–373) among old age men with a high school diploma, and 61 (95% CI 39-83) and 102  
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11 322 (95% CI 89-114) excess deaths among old age men and women respectively with at least some  
12  
13 323 higher education.<sup>8</sup>  
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## 15 325 **V. Discussion**

### 16 326 *Main Findings*

17  
18 327 Our study documents an increase in mortality for persons of Puerto Rican origin in the mainland  
19  
20 328 U.S. during the 6-month period following Hurricane Maria (October 2017 through March 2018).  
21  
22 329 Our findings indicate that measures of excess mortality based on death occurrences in Puerto Rico  
23  
24 330 following the Hurricane may be underestimating total excess mortality by an additional 514 deaths  
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26 331 (95% CI 346 – 681) in the six months following the event, partly due to significant displacement  
27  
28 332 of the Puerto Rican population to the mainland U.S. Crucially, this increase in mortality was  
29  
30 333 concentrated among the most vulnerable populations, with old age adults with lower levels of  
31  
32 334 education seeing the largest increases. These patterns are consistent with excess mortality  
33  
34 335 estimates obtained in Puerto Rico.<sup>20,21</sup> Analyses of these data also provide a rich description of  
35  
36 336 heterogeneity of the event's impacts to yield generalizable knowledge.

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### 37 338 *Contribution, Limitations, and Relationship to the Literature*

38  
39 339 The study contributes to the literature documenting the mortality consequences of Hurricane Maria  
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41 340 in Puerto Rico. Several previous attempts to estimate the mortality effects of Hurricane Maria in  
42  
43 341 Puerto Rico, including the official death toll estimate prepared by the Government of Puerto Rico,  
44  
45 342 used Puerto Rico death registrar data and previous years' mortality rate estimates as a benchmark  
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47 343 to identify periods of excess mortality in Puerto Rico.<sup>17–21</sup> Preferred mortality estimates for the six  
48  
49 344 and seven-month period following the disaster—which considered only deaths registered in Puerto  
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51 345 Rico despite significant population displacement and excluding deaths among the population

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53 <sup>8</sup> We exclude deaths and population counts with missing educational attainment data from this particular analysis.  
54 Accordingly, excess mortality estimates for the group of individuals aged 65+ in Table 3 do not sum to the estimates  
55 reported in Panel C of Table 2. Nevertheless, given the level of precision of our estimates we cannot reject that these  
56 are in the same range.  
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3 346 displaced to the mainland —were as high as 2,975 and 3,400 respectively.<sup>17,20</sup> (We present a  
4 347 summary of the data, techniques, and treatment periods employed in this research in the Online  
5 348 Supplement.) This focus on deaths occurring in the territory resulted in an underestimation of the  
6 349 death toll by approximately 14.7%, which we estimate occurred in the United States. In contrast,  
7 350 Kishore et al. (2018) surveyed a representative sample of households, asking survivors to account  
8 351 for the whereabouts of all people who lived in their community prior to the Hurricane irrespective  
9 352 of the location of the occurrences of death among community members (on the island or  
10 353 elsewhere). Accordingly, they found a mortality rate that yielded an estimate of 4,645 excess  
11 354 deaths (95% CI 793-8,498) on account of Hurricane Maria. Our finding of excess mortality among  
12 355 the population of Puerto Rican origin in the mainland U.S. contributes to explaining the difference  
13 356 in estimates from these two methodological approaches.  
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24 358 An additional contribution of the study is the use of a research design to credibly estimate the  
25 359 excess mortality of displaced and migrant populations during this period while carefully  
26 360 accounting for population displacement following the disaster. Using comparator populations of  
27 361 Cubans and Mexicans in the mainland U.S., our design robustly accounts for different population  
28 362 and mortality trends by age group and gender to account for both displacement and differential  
29 363 mortality among the Puerto Rican population. Our estimates of displacement of the population  
30 364 ages 65 and older of approximately 7.1 percent (40,700 individuals) is in line with the existing  
31 365 literature and supports the consensus using other methodologies that the natural disaster led to  
32 366 displacement in aggregate terms of approximately 4.1-5.6 percent of the total population of Puerto  
33 367 Rico.<sup>32,33</sup> This design, effectively used in related studies and other contexts to account for  
34 368 population movements, is broadly applicable both in other countries and in other disaster contexts  
35 369 (both natural and otherwise), particularly as displacement and mobility becomes an increasingly  
36 370 important feature of natural disasters.<sup>11</sup>  
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48 372 Our study is informative regarding the broad mortality consequences of the disaster among the  
49 373 displaced and migrant population of Puerto Ricans in the U.S. This measure however limits our  
50 374 ability to quantify the elevated burden of disease from morbidity and disability among this  
51 375 population. We also face some limitations in our ability to precisely estimate cause-specific  
52 376 mortality or the causal pathways for such trends. Given the relatively small numbers of deaths in  
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3 377 the population in the period under observation (monthly range 2,119–2,862), generating  
4 378 informative estimates of more finely defined cause-specific mortality is not feasible.

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8 380 Finally, because we use the deaths of persons who are identified as Puerto Rican in their death  
9 381 certificate, our analysis does not allow us to disentangle the excess mortality of displaced  
10 382 populations as opposed to longer-term migrants or second or third-generation individuals of such  
11 383 ancestry. Information on the deaths of Puerto Rico residents in the continental U.S. may be  
12 384 incomplete and/or prone to undercounting if the Puerto Rico residency status of such individuals  
13 385 is under-reported on death certificates. This phenomenon is particularly exacerbated among  
14 386 vulnerable, geographically mobile, migrant populations.<sup>9,10</sup> Nonetheless, the fact our estimated  
15 387 effects are concentrated among vulnerable populations—consistent with the excess mortality  
16 388 estimates obtained for death occurrences in Puerto Rico—supports the view that we mainly capture  
17 389 excess deaths among the sizable population that was displaced to the mainland U.S. following the  
18 390 natural disaster. Future research could undertake epidemiological studies with micro-level data to  
19 391 precisely estimate cause-specific mortality, the causal pathways for such patterns, as well as  
20 392 mortality estimates that includes all hurricane-related deaths according to CDC guidelines for  
21 393 death occurrences in Puerto Rico and in the continental U.S.

22 394  
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24 395 *Policy Implications*

25 396 Our study emphasizes the importance of considering displaced populations in the calculation of  
26 397 post-disaster excess mortality. These populations may suffer from relative inattention in the  
27 398 context of both needs assessment and disaster relief, and we argue that overlooking these provides  
28 399 an incomplete understanding of the magnitude of the health consequences of natural disasters.

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31 401 This analysis suggests the need for not only equitable disaster preparedness, but also the  
32 402 importance of cross-jurisdiction data sharing.<sup>17</sup> These already vulnerable populations may face a  
33 403 number of additional hurdles upon relocation, such as healthcare disruptions and psychological

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<sup>9</sup> Our estimate also excludes persons exposed to the Hurricane, who may have been displaced to other countries, most notably the  
53 neighboring Dominican Republic.

54 <sup>10</sup> While not directly exposed, it is possible that longer-term migrants may have been psychologically or economically affected by  
55 the events in the aftermath of Hurricane Maria, which may also have affected their mortality risk. At the same time, this approach  
56 excludes from the analysis individuals who are not of Puerto Rican origin but who nevertheless may have been in Puerto Rico at  
57 the time of Hurricane, and who may have been displaced in the aftermath of Hurricane Maria.

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3 404 stressors which may exacerbate health impacts of the disaster. Receiving jurisdictions would, thus,  
4 405 benefit from an improved understanding of both the dynamics of post-disaster displacement and  
5 406 its consequences.  
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10 408 Already important efforts exist among jurisdictions in the U.S., such as the State and Territorial  
11 409 Exchange of Vital Events (STEVE) of the National Association for Public Health Statistics  
12 410 Information Systems (NAPHSIS), to facilitate vital records for use by other state-level and  
13 411 territorial public health organizations. However, more coordination is required to speed the flow  
14 412 of data to gain a more comprehensive understanding of the scale of disasters in other countries.  
15 413 Moreover, even among jurisdictions within the U.S., this process can take a considerable amount  
16 414 of time. The speed of flow of vital records depends on the effectiveness of local and county vital  
17 415 registrars to share this information. Ensuring timely exchange of death records among jurisdictions  
18 416 would ensure disaster death toll estimates based on vital records are complete and would hence  
19 417 allow public authorities to have a comprehensive understanding of the scale of the disaster in a  
20 418 timely fashion.  
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## 30 31 420 **Ethics statements**

### 32 33 421 **Patient consent for publication**

34  
35 422 Not required.  
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### 39 423 **Ethics approval**

40  
41 424 Because these data are publicly available and deidentified, this study is considered to be research  
42 425 not involving human subjects as defined by U.S. regulation (45 CFR 46.102[d]).  
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### 45 426 **Contributorship Statement:**

46  
47 427 MM: conceptualisation, data curation, supervision, validation, visualisation, writing – original  
48 428 draft, and writing – review & editing.  
49  
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51 429  
52 430 BM: conceptualisation, data curation, formal analysis, investigation, methodology, visualisation,  
53 431 writing – original draft, and writing – review & editing.  
54

55 432  
56 433 GB: conceptualisation, formal analysis, investigation, methodology, project administration,  
57 434 supervision, validation, visualisation, writing – original draft, and writing – review & editing.  
58  
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3 435  
4 436 **Competing Interests:** Neither author has any competing interests to declare.  
5 437

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7 439  
8 440 **Data Sharing statement**

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11 441 All data relevant to the study are publicly available (and detailed in the article and supplementary  
12  
13 442 materials).

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21 448 Figure 1 Caption:

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24 449 Notes: Standardized monthly mortality from January 2012 to December 2018 (Panel A) and  
25 450 from July 2017 to December 2018 (Panel B). August 2017 is used as the standard mortality rate  
26 451 for both populations.  
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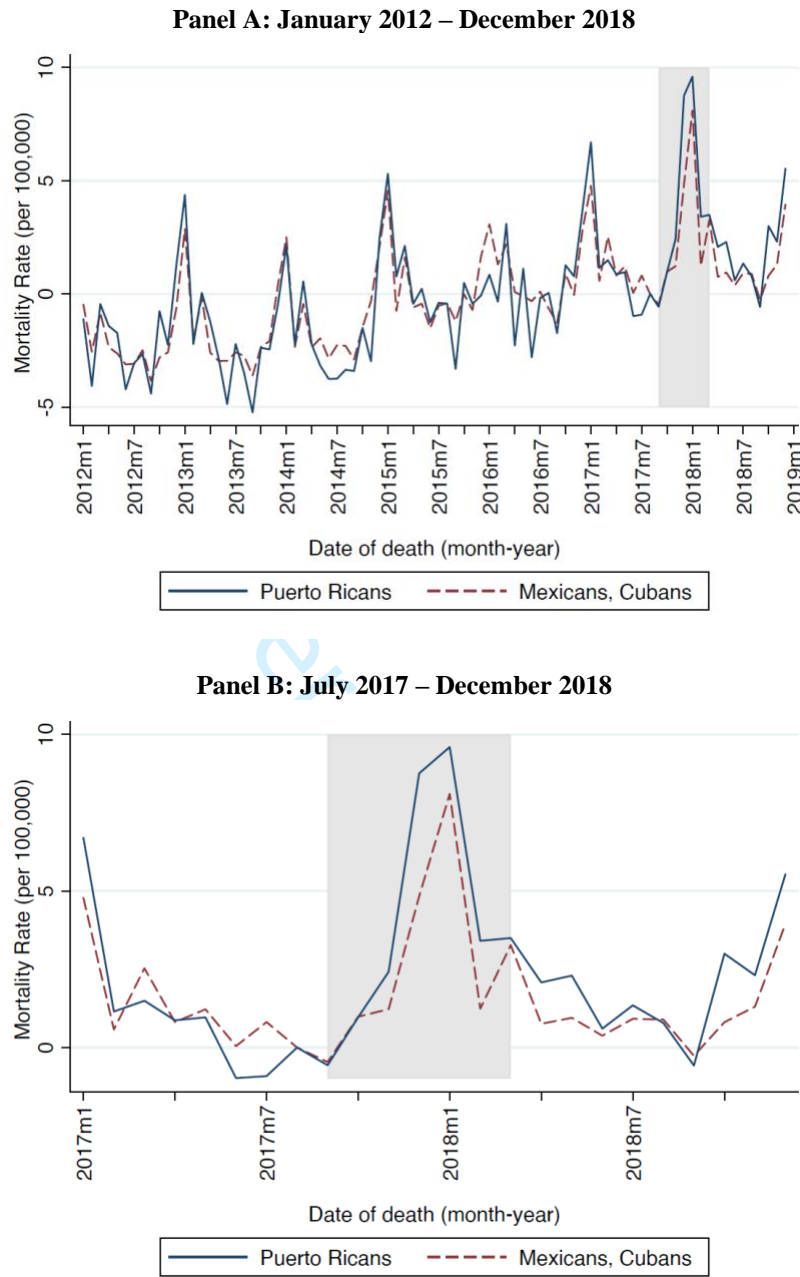
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**Figure 1: Standardized Monthly Mortality Rate of Puerto Ricans vs. Cubans and Mexicans in the US**



Notes: Standardized monthly mortality from January 2012 to December 2018 (Panel A) and from July 2017 to December 2018 (Panel B). August 2017 is used as the standard mortality rate for both populations.

## Supplementary Materials

### A. Additional Figures and Tables

**Table A1. Existing Excess Mortality Estimates of Hurricane Maria<sup>1-5</sup>**

Reference	Main Data Source	Pre-Exposure Period	Exposure Time Period	Estimation Methodology / Design	Preferred Excess Mortality Estimate [95% CI]
Acosta R, Irizarry R. (2018)	Vital records of death occurrences in Puerto Rico	1/1/1985 – 9/20/2017	9/21/2017 – 4/15/2018	Excess mortality	3,400 ± 300
Kishore N. et al. (2018)	Representative, stratified sample household survey	9/20/2016 – 12/31/2016	9/20/2017 – 12/31/2017	Aggregation of mortality reports	4,645 ± 3,852
Santos-Burgoa C. et al. (2018)	Vital records of death occurrences in Puerto Rico	7/1/2010 – 8/31/2017	9/1/2017 – 2/28/2018	Excess mortality	2,975 ± 317
Santos-Lozada A, Howard JT (2018)	Vital records of death occurrences in Puerto Rico	1/1/2010 – 8/31/2017	9/1/2017 – 11/31/2017	Excess mortality	1,139 ± 133
Cruz-Cano R, Mead E (2019)	Vital records of death occurrences in Puerto Rico	1/1/2008 – 8/31/2017	9/1/2017 – 10/31/2017	Excess mortality	1,205 ± 498
Rivera, R., Rolke W. (2019)	Vital records of death occurrences in Puerto Rico	1/1/2015 – 9/19/2017	9/20/2017 – 12/31/2017	Excess mortality	1,318 ± 249

**Notes:** Column 2 reports the main data source used to perform the analysis. Columns 3 and 4 respectively report the period used as a benchmark to identify excess mortality before the Hurricane and the period post-Hurricane during which the period of excess mortality is estimated. Column 5 summarizes the empirical methodology, and column 6 reports the preferred excess mortality estimate and 95% confidence interval.

## B. Methods

### B.1. Temporal Disaggregation of Population Estimates

Annual population estimates of Puerto Ricans, Mexicans and Cubans in the United States were disaggregated to a monthly frequency using the Chow-Lin maxlog method.<sup>6,7</sup> This standard method of temporal disaggregation derives the high-frequency (monthly) data from low frequency (annual) data, allowing for the use of related high-frequency data which the researcher has reason to believe is related to the target time series. In applying this method, the researcher is able to create a high frequency dataset consistent with the initial low-frequency data, but which incorporates the short-term volatility of the related high-frequency data.<sup>1</sup> This is done through a standard least-squares estimation, where the error term is assumed to follow an AR(1) process. In our disaggregation, we chose not to impose a particular short-term volatility, and so regress our low-frequency data for each age-sex-education-Hispanic strata on a constant term, with a mean conversion.

<sup>1</sup> [https://ec.europa.eu/eurostat/cros/content/chow-lin-method-temporal-disaggregation-method\\_en](https://ec.europa.eu/eurostat/cros/content/chow-lin-method-temporal-disaggregation-method_en)

## B.2. Estimation of Excess Mortality Levels – Overall Population and by Subgroup

Our estimation procedure uses the observed age-group-by-gender specific deaths that occurred over the period of October 2018 until March 2018 as well as our estimated coefficients of the differential change in mortality rates of Puerto Ricans in the mainland US ( $\theta_s$  and  $\theta_{st}$ ), to construct estimates of excess mortality for each age-group-gender combination and their corresponding 95 percent confidence interval. To do this:

1. We first obtain the estimates of  $\theta_s$  and  $\theta_{st}$  separately for each age-group-gender combination.
2. We then estimate expected deaths following Maria for each of these subgroups using a non-linear combination of our estimates of the change in mortality rates and the observed deaths. Using nonlinear estimation, we estimate the expected deaths of an age-group-gender combination to be equal to  $\exp(\ln(\text{Observed Deaths}_s) - \theta_s)$ . This is also performed using the period-specific effects ( $\theta_{st}$ ) and observed deaths. This nonlinear estimation procedure also produces standard errors, which are used to construct confidence intervals.
3. We estimate excess deaths by subtracting the expected deaths estimated in (2) from the observed mortality rates for each age-group-gender combination.
4. Finally, to construct the ratio of observed to expected mortality we divide the observed deaths for each age-group-gender combination by our estimate of expected mortality in (2).

To aggregate our age-group-by-gender results to the overall population, we follow a similar procedure:

1. Estimate, as before, our main specification, to obtain a  $\theta_s$  for each of the three age-groups.
2. Aggregate the age group-gender-specific observed deaths to measures at the desired level of aggregation.
3. We then estimate expected deaths following Maria for each of these subgroups using a non-linear combination of our estimates of the change in mortality rates and the observed deaths. Using nonlinear estimation, we calculate, more specifically, the expected deaths of the group,  $h$ , combination to be equal to  $\Sigma_h \exp(\ln(\text{Observed Deaths}_h) - \theta_{sh})$ . This nonlinear estimation procedure also generates standard errors, which are used to construct confidence intervals.
4. Estimate the implied excess deaths by subtracting the expected deaths in (2) from the observed deaths for each age-group:  $\Sigma_h(\text{Observed Deaths}_h) - \Sigma_h \exp(\ln(\text{Observed Deaths}_h) - \theta_{sh})$ .
5. Construct the ratio of observed to expected mortality using the aggregated observed deaths from (2) and the estimated aggregate expected deaths from (3).

## B.3. Estimation of Population Displacement – Overall and by Subgroup

An important consideration in this analysis is our need to estimate the degree of population displacement of the residents of Puerto Rico to the mainland U.S. following the hurricanes. We do so by measuring differential changes in population levels for the Puerto Rican population in the mainland U.S. relative to trends for the comparison groups throughout the period following the Hurricanes.

Again, we make these comparisons by gender and age group, and estimate a system of linear models of the form:

$$\ln(\text{Pop}_{sgmt}) = \tau_s(\text{Maria}_{mt} \times \text{PR}_{sg}) + \mu_{sg} + \delta_{mt} + v_{sgmt}, \quad (\text{B1})$$

where the main outcome and explanatory variables as defined above;  $\mu_{sg}$  are Hispanic group fixed effects;  $\delta_{mt}$  are month-by-year fixed effects; and  $v_{sgmt}$  is the error term; we employ the same estimation procedure. We follow an analogous estimation and aggregation procedure to generate estimates of group-specific and aggregate levels of population displacement in the six-month period following the Hurricane (see Appendix B2 for details). This procedure allows us to both confirm independent estimates of population movements from the territory to the mainland U.S. during this period and to give confidence to the use of population estimates for the estimation of excess mortality rates.

Population displacement was concentrated among the population of individuals ages 65 and older (Table B.1). The population for this group was higher than the expected pattern throughout the October 2017-March 2018 period: the point estimates imply a population increase of 6.0 percent among men (95% CI 1.02 – 1.11) and of 9.7 percent among women (95% CI 1.04 – 1.17) for women. In terms of the temporal pattern, we detect increases in population levels of 2.5 and 14.6 percent among both older age women and men starting in November 2017 until March 2018, with



consistently greater statistical precision among the former group.<sup>2</sup> In contrast, we find no robust evidence of increases in population from the expected pattern for the younger age populations throughout this period. These estimates are consistent with existing evidence that a large share of the post-disaster displacement among the Puerto Rico-based population occurred among the elderly.<sup>2</sup>

**Table A2. Existing Displacement Estimates of Hurricane Maria<sup>8-13</sup>**

Reference	Data source	Treatment Period	Preferred Displacement Estimate
Meléndez and Hinojosa (2017)	American Community Survey	2017-2019	470,335 (14%)
Echenique and Melgar (2018)	Mobile Phone	10/2017 – 02/2018	400,000 (6%)
Alexander, Polimis, and Zagheni (2019)	Facebook, American Community Survey	10/2017 – 01/2018	185,200 (17%)
Santos-Lozada (2019)	Census, Air Travel	2017	154,575
United States Census Bureau (2019)	American Community Survey, Puerto Rico Community Survey	2017 – 2018	142,000 (4.4%)
Acosta et al. (2020)	American/Puerto Rico Community Survey	07/2017-07/2018	129,848 (4%)
	Air Travel	07/2017-07/2018	168,295 (5%)
	Mobile Phone	07/2017-05/2018	235,375 (8%)
	Social Media	08/2017-08/2018	475,779 (17%)

**Notes:** Column 2 reports the main data sources used to estimate displacement effects of Hurricane Maria. The primary treatment period of each paper is indicated in column 3. Column 4 provides the preferred displacement estimate (with the percent change in parentheses).

Table A2 provides a summary of existing displacement estimates from Hurricane Maria. The patterns we document are largely consistent with the remainder of the literature, although with notable exceptions. One reason for these underlying differences is the source(s) of data used in the analysis. For example, Alexander, Polimis and Zagheni (2019), find a 17% increase in the number of Puerto Rican migrants combining Facebook and American Community Survey data. While the magnitude of this estimate is greater than ours, it is consistent with estimates from Acosta et al. (2020) which similarly use social media data and estimate a 17% change in displacement.<sup>3</sup> These social media data have the advantage of providing estimates of population at a time granularity finer than 1-year (as in the case of the ACS and PRCS). One limitation of this type of data, however, is the under-representation or exclusion of older individuals. While Alexander, Polimis and Zagheni (2019) find that changes in population were disproportionately driven by those age 15-30, their analysis does not include individuals over the age of 60. Our estimates suggest that this is an important subpopulation to consider when estimating displacement.

Nevertheless, Acosta et al. (2020) document that using the ACS data generates the smallest estimates of population displacement, with airline passenger and mobile phone data generating larger displacement at a finer time granularity. Finally, data from Facebook shows the largest declines (475,779 – approximately 17%) in population in Puerto Rico

<sup>2</sup> Results available upon request from corresponding author.

<sup>3</sup> These estimates are similar in magnitude to population projections made by Meléndez and Hinojosa (2017), although are substantially larger than estimates using ACS data from the United States Census Bureau (2019), which estimates only 142,000 Puerto Ricans were displaced.

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2  
3 following the hurricane. Similar estimates are provided in Echenique and Melgar (2018), who use mobile phone  
4 tracking data to understand population dynamics. While they provide rich information on the destination of these  
5 displaced individuals, little is known about their demographic characteristics.  
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#### 8 **B.4. Evaluation of Research Design – Placebo Tests of Pre-Event Differential Trends in Mortality**

9 In our interrupted time series / differences-in-differences design, we can test whether there were differences in the  
10 trends in mortality rates between the population of Puerto Rican vs. Mexican/Cuban population prior to the hurricanes  
11 which occurred in September 2017.  
12

13 We implement a series of placebo tests to evaluate whether there are significant increases in mortality of the Puerto  
14 Rican population relative to that of the comparison group. We drop all data from the period September 2017 onwards,  
15 and then create 6-month treatment windows for each period on our sample to mirror our main analysis. We generate  
16 68 placebo differences-in-differences estimates (for event windows starting in January 2012 until August 2018).  
17

18 We compare our true estimate of the change in the mortality rate coefficients  $\theta_s$  to the other placebo estimates obtained,  
19 reporting the percentile rank of the coefficient from the permutation test as well as the approximate p-value. In  
20 addition, we show histograms of the distribution of placebo-based results (see Figure B.1). We conduct this procedure  
21 both for the overall population (Panel A) as well as for individuals ages 65 and older (Panel B).  
22

23 The true estimate of  $\theta_s$  ( $= 0.03732$ ) for the period October 2017 – March 2018 is ranked first in the distribution of  
24 placebo estimates. Specific placebo estimates for the period Oct. 2013-Mar. 2014, Oct. 2014-Mar. 2015, and Oct.  
25 2015-Mar. 2016, and Oct. 2016-Mar. 2017 are  $-0.0117$ ,  $0.0263$ ,  $-0.0113$ , and  $0.0325$ , respectively. For the population  
26 of adults aged 65 and over, the true estimate of  $\theta_s$  ( $= 0.0682$ ) is similarly ranked first in the distribution of placebo  
27 estimates, and the distribution of placebo estimates is centered around zero.<sup>4</sup> Overall, this analysis supports the  
28 assessment that there are common mortality trends across the two groups before the event, and that a significant  
29 deviation takes place in a pronounced manner in the six-month window following these events.  
30

#### 31 **B.5. Estimation of Excess Mortality Levels by Cause of Death**

32 We estimate models of mortality by main cause of death following the hurricanes in order to evaluate possible  
33 pathways connecting the observed excess mortality to the natural disaster. We estimate sets of models as in equation  
34 (1) using the natural logarithm of death counts by category as dependent variables, and follow the same procedure  
35 described in Section B.1 above to generate aggregate estimates of excess mortality by cause of death. We group causes  
36 of death into ten (10) main underlying categories using the NCHS 39-group recode of the ICD 10 Classifications:  
37 heart disease (20-26), cancer (5-15), other diseases (37), external (38-42), liver/kidney related (29-31), respiratory  
38 (27-28), diabetes (16), and Tuberculosis/Syphilis/HIV (1-3). We conduct this analysis both for the overall population  
39 as well as for individuals ages 65 and older (see Table B.2).  
40

41 Excess mortality was concentrated in deaths related to heart disease: the point estimates imply a ratio of observed to  
42 expected deaths of 1.06 among the overall population (95% CI 1.04 – 1.08) and of 1.11 among the adults ages 65  
43 years and older (95% CI 1.07 – 1.14). In overall terms, we also estimate an increase in deaths due to diabetes and  
44 external factors; the ratio of observed to expected deaths are respectively 1.03 (95% CI 1.01 – 1.04) and 1.10 (95%  
45 CI 1.06 – 1.14). Among the old age population, the point estimates of the ratio of observed to expected deaths suggest  
46 increases in cancer (1.05 (95% CI 1.03 – 1.08)), diabetes (1.09 (95% CI 1.08 – 1.09)), and mortality related to other  
47 conditions (1.09 (95% CI 1.05 – 1.13)). Changes in mortality rates related to renal and respiratory conditions are  
48 positive but not significant at conventional confidence levels. These patterns are consistent with the distinct  
49 experiences that are specific to relocation among displaced populations such as additional psychological stressors and  
50 disruption in access to healthcare services as well as changes in their living conditions and social networks.<sup>18,19</sup>  
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55 <sup>4</sup> Table 2 reports estimates of 0.073 and 0.064 for men and women ages 65 and over. The estimate for the population ages 65 and  
56 over of both genders is  $\theta_s = 0.0682$ .  
57  
58  
59

**Table B.1:** Estimates of Displacement of Puerto Rican Population to the Mainland US, by Age Group and Sex (October 2017 – March 2018)

	$\Delta \ln(\text{Population})$ [95% CI]	Population (100,000's)	Expected Pop.	Excess Pop [95% CI]	Ratio of Observed to Expected Pop. [95% CI]
	(1)	(2)	(3)	(4)	(5)
<b>Panel A: 0-39 Years of Age</b>					
Men	0.000 (-0.218, 0.218)	18.782	18.783	-0.001 (-1.869, 1.868)	1.00 (0.90, 1.10)
Women	-0.031 (-0.239, 0.178)	17.635	18.189	-0.554 (-2.282, 1.174)	0.97 (0.87, 1.06)
<b>Panel B: 40-64 Years of Age</b>					
Men	0.000 (-0.061, 0.061)	7.626	7.625	0.001 (-0.211, 0.213)	1.00 (0.97, 1.03)
Women	-0.004 (-0.024, 0.016)	7.967	8.000	-0.033 (-0.107, 0.042)	1.00 (0.99, 1.01)
<b>Panel C: <math>\geq 65</math> Years of Age</b>					
Men	0.060 (-0.037, 0.157)	2.222	2.092	0.130 (0.037, 0.222)	1.06 (1.02, 1.11)
Women	0.097 (-0.037, 0.231)	3.002	2.275	0.277 (0.111, 0.443)	1.10 (1.04, 1.17)
<b>Panel D: All</b>					
Men	0.005 (-0.052, 0.061)	28.630	28.500	0.130 (-1.482, 1.742)	1.01 (0.95, 1.06)
Women	-0.011 (-0.057, .035)	28.604	28.913	-0.309 (-1.636, 1.017)	0.99 (.94, 1.04)

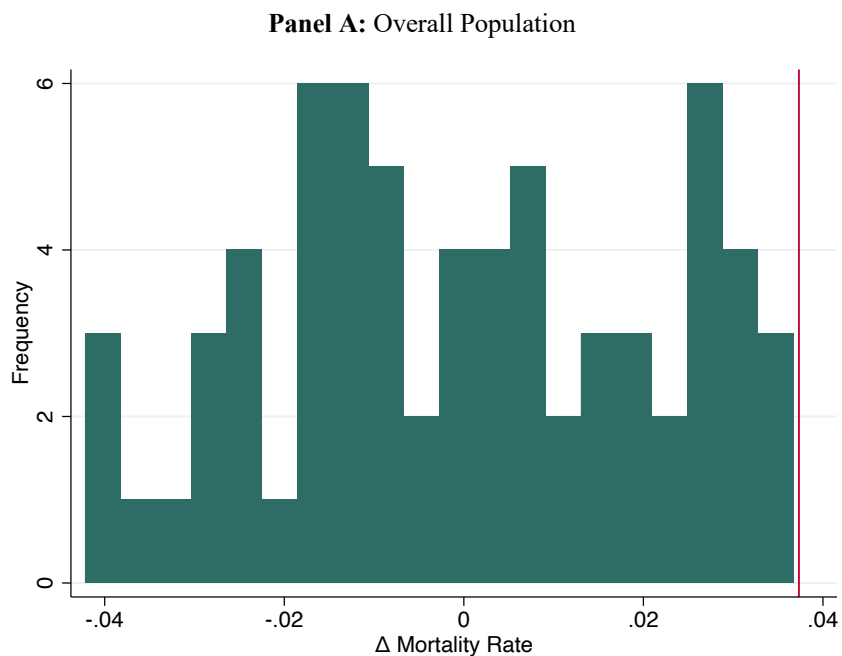
**Notes:** Column 1 reports estimates of the difference in the natural logarithm of the population of Puerto Ricans relative to Cubans and Mexicans in the mainland U.S. based on the aggregation of OLS estimates from equation 1 estimated for each gender-by-age group, as well as 95 percent confidence intervals in parentheses. Column 2 reports estimates of the overall population of Puerto Ricans in the mainland by gender and age group. Columns 3, 4, and 5 respectively report estimates of expected population, excess population (displacement), and the ratio of observed to expected population calculated from the estimated population (col. 2) and estimates of the relative change in population (col. 1); 95 percent confidence intervals of the level of excess population (displacement) and of the ratio of observed to expected population are reported in parentheses.

**Table B.2:** Excess Mortality of the Puerto Rican Population in the Mainland US by Cause of Death, Overall and Old-Age Population (October 2017 – March 2018)

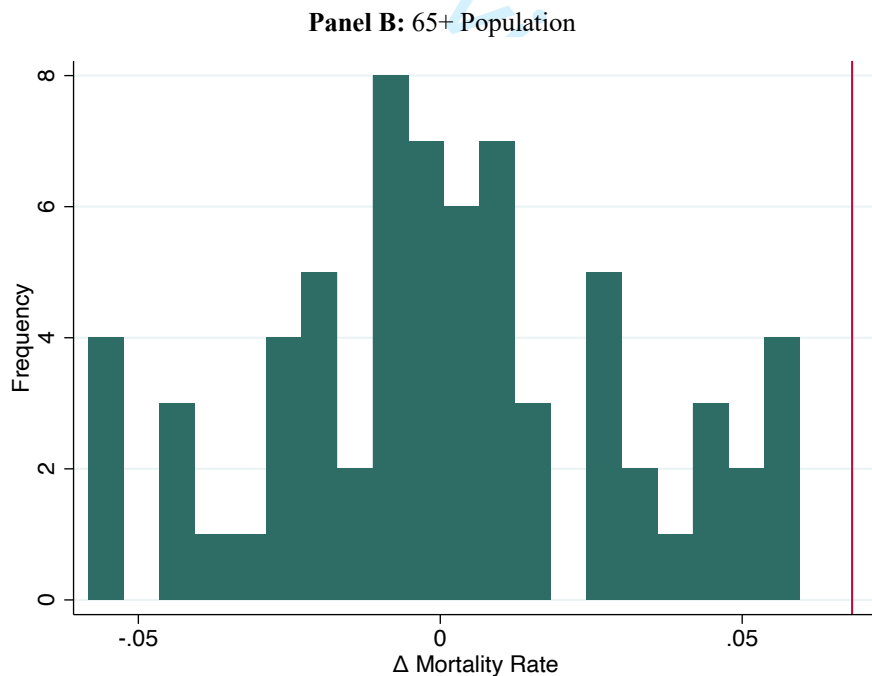
	Observed Deaths (1)	Excess Deaths [95% CI] (2)	Ratio of Observed to Expected Mortality [95% CI] (3)		Observed Deaths (1)	Excess Deaths [95% CI] (2)	Ratio of Observed to Expected Mortality [95% CI] (3)
<b>Panel A: All</b>				<b>Panel B: ≥ 65 Years of Age</b>			
Heart Disease	3,980	223	1.06 (1.04, 1.08)	Heart Disease	3,086	297	1.11 (1.07, 1.14)
Cancer	2,488	29	1.01 (1.00, 1.02)	Cancer	1,624	80	1.05 (1.03, 1.08)
Other	2,577	-1	1.00 (0.94, 1.06)	Other	1,853	154	1.09 (1.05, 1.13)
External	1,627	143	1.10 (1.06, 1.14)	External	282	39	1.21 (1.05, 1.37)
Liver/Kidney	535	-48	0.92 (0.90, 0.94)	Liver/Kidney	301	28	1.10 (0.91, 1.30)
Respiratory	837	15	1.02 (0.84, 1.20)	Respiratory	661	76	1.13 (0.93, 1.33)
Diabetes	601	15	1.03 (1.01, 1.04)	Diabetes	402	32	1.09 (1.08, 1.09)
TB/Syphilis/HIV	118	-1	1.00 (0.92, 1.07)	TB/Syphilis/HIV	49	6	1.14 (1.13, 1.15)

**Notes:** Column 1 reports observed mortality by cause of death of the Puerto Rican population, overall (left panel) and for those 65 years and older (right panel), in the mainland U.S. Columns 2 and 3 respectively report estimates of excess deaths and the ratio of observed to expected deaths calculated from observed deaths (col. 1) and estimates of changes in mortality rates by cause of death based on equation 1; 95 percent confidence intervals of the level of the ratio of observed to expected deaths are reported in parentheses.

**Figure B.1:** Distribution of Placebo Tests for Evaluation of Differences-in-Differences Research Design



Notes: Distribution of placebo effects on the change in the natural logarithm of deaths among Puerto Ricans relative to Cubans and Mexicans in the mainland U.S. (comparable to true estimate in Table 1, Panel B:  $\theta_s = 0.03732$  indicated by the red vertical line).



Notes: Distribution of placebo effects on the change in the natural logarithm of deaths among Puerto Ricans relative to Cubans and Mexicans in the mainland U.S. age 65+ (comparable to true estimate  $\theta_s = 0.0682$  indicated by the red vertical line).

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60STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

	<b>Item No</b>	<b>Recommendation</b>	
<b>Title and abstract</b>	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	Page 1, Title
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	Page 1, Summary
<b>Introduction</b>			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Page 2, Paragraph 1-3
Objectives	3	State specific objectives, including any prespecified hypotheses	Page 2, Paragraph 4
<b>Methods</b>			
Study design	4	Present key elements of study design early in the paper	Page 3, Paragraph 1
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Page 1, Summary
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants	Page 3, Section II, Paragraph 1
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Page 3, Section II, Paragraph 1-2
Data sources/measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Page 3, Section II, Paragraph 1-2
Bias	9	Describe any efforts to address potential sources of bias	Page 4 paragraph 2-3, page 5 paragraph 1
Study size	10	Explain how the study size was arrived at	n/a
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Page 3, Section II, Paragraph 2
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	Page 4, Section III
		(b) Describe any methods used to examine subgroups and interactions	Page 4, Section III, Paragraph 1
		(c) Explain how missing data were addressed	Page 3, Section II, Paragraph 3
		(d) If applicable, describe analytical methods taking account of sampling strategy	N/A
		(e) Describe any sensitivity analyses	N/A
<b>Results</b>			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the	Page 5, Section IV, Paragraph 1

		study, completing follow-up, and analysed	
		(b) Give reasons for non-participation at each stage	n/a
		(c) Consider use of a flow diagram	n/a
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Page 5, Section IV, Paragraph 1
		(b) Indicate number of participants with missing data for each variable of interest	N/A
Outcome data	15*	Report numbers of outcome events or summary measures	Page 5, Section IV, Paragraph 1
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Page 5, Section IV
		(b) Report category boundaries when continuous variables were categorized	Page 3, Section II, paragraph 5
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Page 4 paragraph 6
<b>Discussion</b>			
Key results	18	Summarise key results with reference to study objectives	Page 6, paragraph 3
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Page 6, paragraph 4
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Page 6
Generalisability	21	Discuss the generalisability (external validity) of the study results	Page 6, paragraph 2
<b>Other information</b>			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	N/A

\*Give information separately for exposed and unexposed groups.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at [www.strobe-statement.org](http://www.strobe-statement.org).