Supplementary Materials

A. Additional Figures and Tables

Table A1. Existing Excess Mortality Estimates of Hurricane Maria[1–5]

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.[6,7] 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.[1] 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.

[1] 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 (θ_s and θ_{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 θ_s and θ_{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 $exp(ln(\text{Observed Death}_s) - \theta_s)$. This is also performed using the period-specific effects (θ_{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 θ_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 $\Sigma_h exp(ln(Obsverved\ Deaths_h) - \theta_{sh})$. 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: $\Sigma_h(Obsverved\ Deaths_h) - \Sigma_h\ exp(ln(Obsverved\ Deaths_h) - \theta_{sh})$.
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:

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

where the main outcome and explanatory variables as defined above; μ_{sg} are Hispanic group fixed effects; δ_{mt} are month-by-year fixed effects; and ν_{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.[2] 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.[2]

Table A2. Existing Displacement Estimates of Hurricane Maria[8–13]

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.[3] 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

[2] Results available upon request from corresponding author.

[3] 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.

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

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

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

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

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

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

B.5. Estimation of Excess Mortality Levels by Cause of Death

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

Excess mortality was concentrated in deaths related to heart disease: the point estimates imply a ratio of observed to expected deaths of 1·06 among the overall population (95% CI 1·04 – 1·08) and of 1·11 among the adults ages 65 years and older (95% CI 1·07 – 1·14). In overall terms, we also estimate an increase in deaths due to diabetes and external factors; the ratio of observed to expected deaths are respectively 1·03 (95% CI 1·01 – 1·04) and 1·10 (95% CI 1·06 – 1·14). Among the old age population, the point estimates of the ratio of observed to expected deaths suggest 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 conditions (1·09 (95% CI 1·05 – 1·13)). Changes in mortality rates related to renal and respiratory conditions are positive but not significant at conventional confidence levels. These patterns are consistent with the distinct experiences that are specific to relocation among displaced populations such as additional psychological stressors and disruption in access to healthcare services as well as changes in their living conditions and social networks.[18,19]

[4] 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 over of both genders is θ_s = 0.0682.

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

	Δ ln(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)
Panel A: 0-39 Years of Age					
Men	0.000	18.782	18.783	-0.001	1.00
	(-0.218, 0.218)			(-1.869, 1.868)	(0.90, 1.10)
Women	-0.031	17.635	18.189	-0.554	0.97
	(-0.239, 0.178)			(-2.282, 1.174)	(0.87, 1.06)
Panel B: 40-64 Years of Age					
Men	0.000	7.626	7.625	0.001	1.00
	(-0.061, 0.061)			(-0.211, 0.213)	(0.97, 1.03)
Women	-0.004	7.967	8.000	-0.033	1.00
	(-0.024, 0.016)			(-0.107, 0.042)	(0.99, 1.01)
Panel C: ≥ 65 Years of Age					
Men	0.060	2.222	2.092	0.130	1.06
	(-0.037, 0.157)			(0.037, 0.222)	(1.02, 1.11)
Women	0.097	3.002	2.275	0.277	1.10
	(-0.037, 0.231)			(0.111, 0.443)	(1.04, 1.17)
Panel D: All					
Men	0.005	28.630	28.500	0.130	1.01
	(-0.052, 0.061)			(-1.482 ,1.742)	(0.95, 1.06)
Women	-0.011	28.604	28.913	-0.309	0.99
	(-.057, .035)			(-1.636 ,1.017)	(.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.

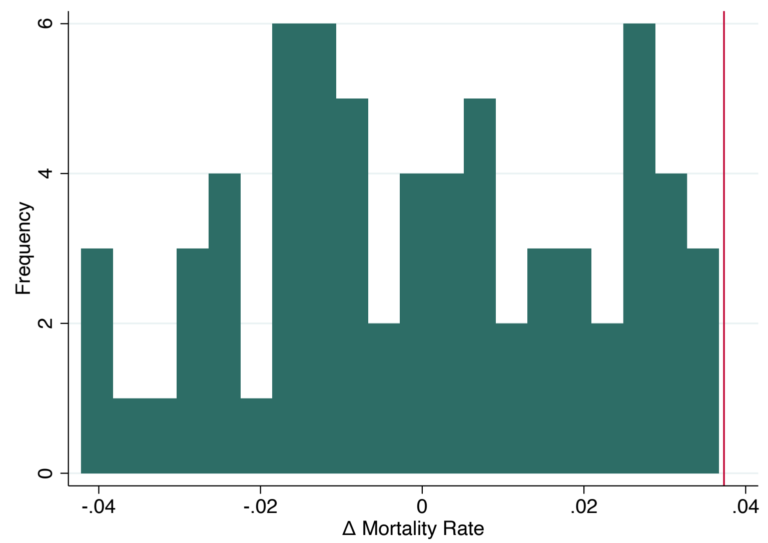
Table B.2: Excess Mortality of the Puerto Rican Population in the Mainland US by Cause of Death, Overall and Old-Age Population (October 2017 – March 2018)

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

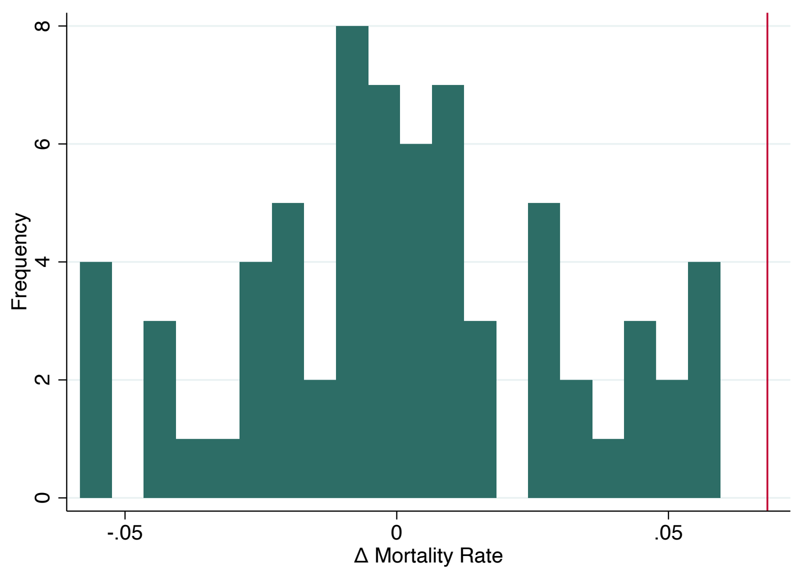
Figure B.1: Distribution of Placebo Tests for Evaluation of Differences-in-Differences Research Design

Panel A: Overall Population



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).

Panel B: 65+ Population



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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