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DISPLACEMENT AND MORTALITY AFTER A DISASTER: DEATHS OF PUERTO RICANS IN THE UNITED STATES POST-HURRICANE MARIA

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

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Abstract

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. While all victims of natural disasters face common challenges, displaced populations undergo distinct experiences that are specific to their relocation. 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. We use an interrupted time-series design to analyze all-cause mortality of Puerto Ricans in the U.S. to determine death occurrences of Puerto Ricans on the mainland U.S. following the arrival of Hurricane Maria in Puerto Rico in September 2017. Hispanic Origin data from the National Vital Statistics System and from the Public Use Microdata Sample of the American Community Survey are used to estimate monthly origin-specific mortality rates for the period 2012 to 2018. We estimated log-linear regressions of monthly deaths of persons of Puerto Rican vs. other Hispanic groups by age group, gender, and educational attainment. We found an increase in mortality for persons of Puerto Rican origin during the 6-month period following the Hurricane (October 2017 through March 2018), suggesting that deaths among these persons were 3.7% (95% CI: 0.025-0.049) higher than would have otherwise been expected. In absolute terms, we estimated 514 excess deaths (95% CI 346 − 681) of persons of Puerto Rican origin that occurred on the mainland U.S., concentrated in those aged 65 years or older. Our findings suggest an undercounting of previous deaths as a result of the hurricane due to the systematic effects on the displaced and resident population in the mainland U.S. Displaced populations are frequently overlooked in disaster relief and subsequent research. Ignoring these populations provides an incomplete understanding of the damages and loss of life.

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I. 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.[1,2] The consequences for human lives and the economic costs associated with these disasters are high.[3,4] 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.[3,5,6]

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.[4] 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.[5]

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.[6] 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.[7] In spite of these methodological limitations, this literature has shaped our understanding of mortality patterns among displaced populations. If conclusions about these forms

[4] See Uscher-Pines (2009) and Frankenberg, Laurito, and Thomas (2015) for systematic reviews of the literatures on the health effects of relocation following disaster and of the demographic consequences of disasters more generally.[18,19]

[5] 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.[19] Subsequent studies find higher mortality risks for specific displaced subpopulations such as among relocated institutionalized elderly; see Willoughby et al. for a systematic review.[20]

[6] 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.[6,21]

[7] 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.[6,17,18,21–26]

of vulnerability do not transcend specific groups and cannot be replicated more generally, their informativeness in planning for or responding to the needs of at-risk populations—monitoring, assessment, programming of interventions and the targeting of social safety nets—is compromised.

In this article, we contribute to research on the mortality consequences of extreme environmental hazards among displaced populations in host communities.[8] We study the excess mortality experienced by Puerto Ricans in the mainland U.S. following the devastation caused in Puerto Rico by Hurricanes Irma and Maria in September 2017. We combine administrative death records data from the U.S. National Vital Statistics System together with population estimates using repeated cross-sections of the Public Use Microdata Sample of the American Community Survey to estimate monthly immigrant-origin group-specific mortality rates by age, gender, and educational attainment for the period 2012 to 2018 in the mainland U.S. Using these data, which is representative of the at-risk population, we conduct analyses that measure outcomes consistently for individuals from the group affected by the disaster relative to those of comparable populations.

We use an interrupted time-series differences-in-differences design to examine patterns of all-cause mortality of Puerto Ricans in the United States during the months following the Hurricane, using mortality trends for Cuban and Mexican populations in the mainland U.S.—whose countries of origin or ancestry were not affected by extreme hurricanes that year (or limited population displacement to the U.S. as a result of these events) and who had historically similar mortality trends preceding the event—as a comparison group. The design we employ robustly accounts for different mortality trends by age group and gender to identify the potentially greater mortality risk among the Puerto Rican population in the mainland.

Our study documents a systematic increase in mortality among Puerto Ricans on the mainland in the six-month period in the aftermath of the Hurricanes that is concentrated among old-age populations. Analyses of these data also provide a rich description of heterogeneity of the event's impacts to yield generalizable knowledge.

[8] We conceptualize post-disaster mobility as a coping strategy that occurs along a spectrum from forced displacement to largely voluntary migration.[6,27–29]

From a substantive point of view, we add to the literature on the effects of Hurricane Maria on Puerto Rico. The consensus from existing research documenting excess mortality in the aftermath of the Hurricanes—based on death occurrences that happened physically in the archipelago of Puerto Rico—is that well over one thousand people died in Puerto Rico and likely more than three thousand lost their lives (see Supplementary Materials Table A1).[7–11] However, to date, no systematic attempt had been made to consider deaths that may have occurred on the mainland United States as a result of this natural disaster.

II. Data and Descriptive Statistics

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

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

We employ a standard temporal disaggregation method for time series data based on dynamic models to generate stratum-specific population measures for each month.[12,13] The technique exploits the time-series relationship of the available low-frequency data using a regression model with autocorrelated errors generated by a first-order autoregressive process. The reference period of the ACS is the 12-month calendar year. As a result, we also restrict the 12-month average population estimate to equal the annual ACS-based population estimate; see Supplementary Materials for details.

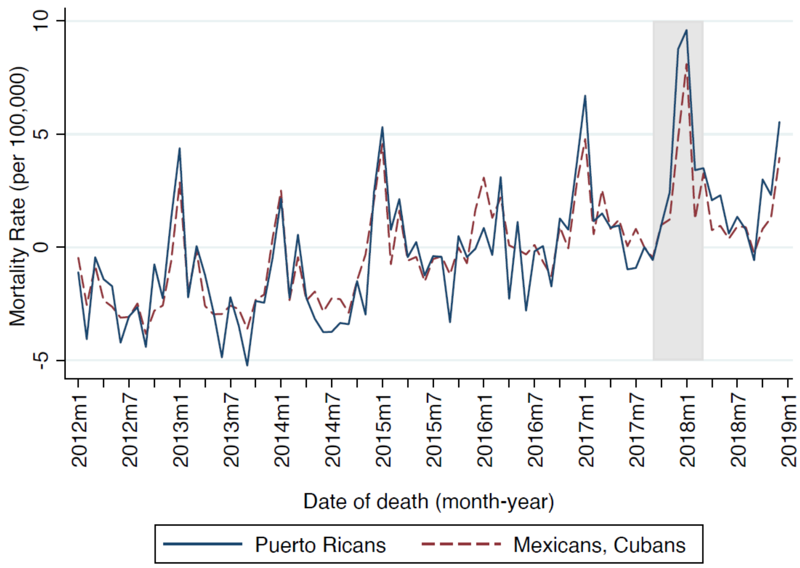
Because these data are publicly available and deidentified, this study is considered to be research not involving human subjects as defined by U.S. regulation (45 CFR 46.102[d]).

We compare mortality outcomes pre and post September 2017 among the Puerto Rican population in the mainland U.S. relative to other Hispanic groups in the country. In Panel A of Figure 1 we examine trends in the overall mortality rate of Puerto Ricans in the mainland U.S. (blue solid line) during January 2012-December 2018 and that of Cubans and Mexicans (red dashed line) throughout the same period. Between January of 2012 and August 2017, the mortality rate among individuals of Puerto Rican ancestry averaged 38·86 per 100,000. In contrast, the mortality rate among Cubans and Mexicans throughout this period was 31·48 per 100,000. In spite of this difference in the level of mortality, the two groups experienced very similar seasonal patterns and trends in their mortality in the period up to September 2017, when Puerto Rico was severely affected by Hurricanes Irma and Maria (Figure 1, panel A).

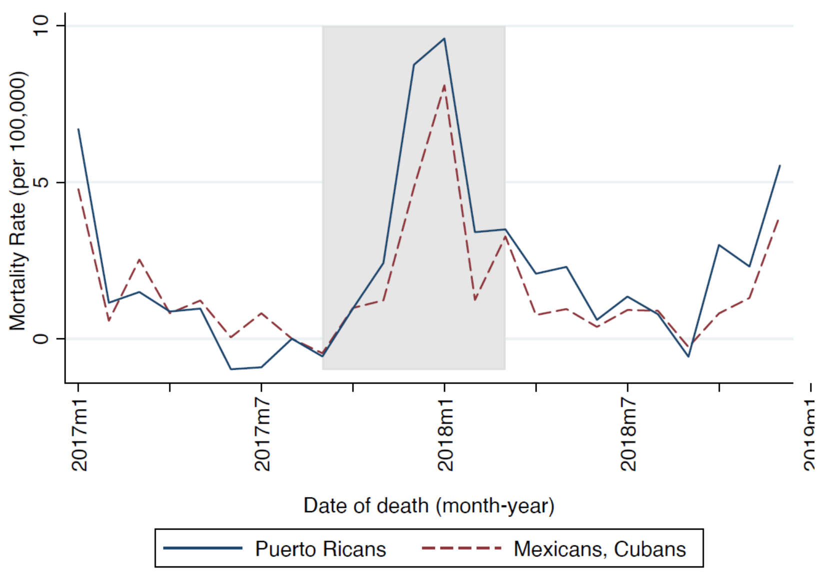
Following these events, we observe a modest trend break in the mortality rate of Puerto Ricans relative to that of Cubans and Mexicans, in the 0·08-4·03 deaths per 100,000 range (Figure 1, panel B). The figure helps validate the research design (see Section III below). Moreover, it reveals the mortality rate gap to be most pronounced during the October 2017 through March 2018; we use this post-Hurricane six-month event window to capture estimates of excess mortality for the Puerto Rican population in the mainland U.S.

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

Panel A: January 2012 – December 2018



Panel B: July 2017 – December 2018



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.

III. Methods

Our empirical strategy consists of a difference-in-differences design. We compare differences in the mortality rates of Puerto Ricans before and after September 2017 relative to that of Cubans and Mexicans, comparable Hispanic groups in the U.S., during the January 2012-December 2018 time period. In doing so, we effectively use the mortality outcomes of the comparison groups to control for seasonality and period-specific effects.[9] We make these comparisons by gender and age group, estimating a system of six (6) linear models of the form:

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

where d_{sgmt} is the number of deaths of individuals from gender-age group stratum s and Hispanic group g in month m and year t; Maria_{mt} is an indicator variable for the 6-month period from October 2017 to the March 2018; PR_{sg} is an indicator variable for Puerto Rican origin; Pop_{sgmt} is the population level estimate for each Hispanic group g over time; α_{sg} are Hispanic group fixed effects; γ_{mt} are month-by-year fixed effects; and ε_{sgmt} is the error term. This model richly captures seasonality as well as other time trends for each gender-by-age stratum, and accounts for differences in the mortality rate levels between Puerto Ricans and other Hispanic groups. We estimate the models as a system of equations allowing for autocorrelation of the error terms by clustering standard errors at the Hispanic group level.[14–16] This procedure also allows us to account for the correlation of mortality rates across age groups and gender within each Hispanic group as well as the autocorrelation of mortality for each group, and to generate estimates of aggregate excess mortality for the population based on the stratum-specific models.

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

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

where $\text{I}\{g = \text{PR}_\text{g}\} \cdot \text{I}\{t = 1,2,\ldots,6\}$ is a vector capturing the interaction of the PR indicator with an indicator variable for each month from October 2017 to March 2018, with September 2017 – the month of the event – as the base period. All other variables are as defined above in equation (1). The vector θ_{st} captures the period-specific effects for each month during the 6-month window described earlier.

[9] The results are robust to restricting the sample to start in later years (i.e., 2013, 2014), but with somewhat lower levels of precision.

Our estimation procedure uses the observed age-group-by-gender specific deaths that occurred over the period of September 2017 until March 2018 as well as our estimated coefficients of the differential change in mortality rates of Puerto Ricans in the mainland U.S. (θ_s, θ_{st}), to construct estimates of excess mortality for each age-group-sex combination and their corresponding 95 percent confidence interval. We follow an analogous procedure to generate estimates of excess mortality for the population in overall terms. See Supplementary Materials for details of the estimation and aggregation procedures.

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. This methodology, described in more detail the Supplementary Materials, generates estimates of population displacement, or the population in excess of what would have otherwise been expected. 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.

IV. Results

14,010 individuals of Puerto Rican background died in the mainland U.S. between October 2017 and March 2018 (Table 1); 7,505 (53·6%) were men and 6,505 (46·4%) were women (Table 2); 9,045 (64.6%) were adults aged 65 years or older (Table 3). In contrast, 10,866-12,832 deaths occurred among this population in the six-month period between October and March in the 2012-13 to 2016-17 years, the period of observation before the hurricane. We estimated that there were approximately 5·631 million individuals of Puerto Rican origin in the mainland U.S. in August 2017, and by March 2018, this number was 5·783 million—an increase of approximately 152,000 individuals, or a 2·7 percent population increase (Table 1).

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)	Δ Mortality Rate [95% CI] (2)	Population (100,000's) (3)	Expected Deaths (4)	Excess Deaths (5)	Ratio of Observed to Expected Mortality (6)
Panel A: Month-Specific Estimates						
October 2017	2,093	0·022	56·596	2,047	46	1·02
		(-0·006, 0·051)			(-11·7, 104·1)	(0·99, 1·05)
November 2017	2,182	0·059	56·767	2,056	126	1·06
		(0·041, 0·78)			(87·1, 164·7)	(1·04, 1·08)
December 2017	2,551	0·065	56·974	2,391	160	1·07
		(0·048, 0·082)			(119·4, 200·7)	(1·05, 1·09)
January 2018	2,624	0·012	57·524	2,592	32	1·01
		(-0·014, 0·039)			(-36·1, 100·5)	(0·99, 1·04)
February 2018	2,275	0·059	57·708	2,145	130	1·06
		(0·035, 0·083)			(78·1, 182·4)	(1·03, 1·09)
March 2018	2,285	0·004	57·83	2,276	9	1
		(-0·008, 0·016)			(-19·1, 36·8)	(0·99, 1·02)
Panel B: Aggregate Estimates						
October 2017 - March 2018	14,010	0·037	57·233	13,496	514	1·04
		(0·025, 0·050)			(346·5, 681·0)	(1·03, 1·05)
October 2017 - December 2017	6,826	0·037	56·779	6,581	245	1·04
		(0·024, 0·049)			(163·6, 326·9)	(1·02, 1·05)

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

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

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

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

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

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)	Δ Mortality Rate [95% CI] (2)	Population (100,000's) (3)	Expected Deaths (4)	Excess Deaths (5)	Ratio of Observed to Expected Mortality (6)
Panel A: 0-39 Years of Age						
Men	936	-0·023	18·782	957·6	-22	0·98
		(-0·026, -0·019)			(-23, -20)	(0·98, 0·98)
Women	433	0·011	17·635	428·2	5	1·01
		(-0·106, 0·129)			(-18, 28)	(0·96, 1·07)
Panel B: 40-64 Years of Age						
Men	2320	-0·005	7·626	2332·5	-12	0·99
		(-0·016, 0·005)			(-24, -1)	(0·99, 1·00)
Women	1276	-0·041	7·967	1329·1	-53	0·96
		(-0·086, 0·004)			(-80, -26)	(0·94, 0·98)
Panel C: ≥ 65 Years of Age						
Men	4249	0·073	2·222	3950·9	298	1·08
		(0·008, 0·137)			(182, 414)	(1·04, 1·.11)
Women	4796	0·064	3·002	4498	298	1·07
		(0·041, 0·088)			(250, 346)	(1·05, 1·08)
Panel D: All						
Men	7505	0·036	28·63	7241	264	1·04
		(0·022, 0·050)			(162, 366)	(1·02, 1·05)
Women	6505	0·039	28·604	6255	250	1·04
		(0·028, 0·050)			(179, 320)	(1·03, 1·05)

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)	Δ Mortality Rate [95% CI] (2)	Population (100,000's) (3)	Expected Deaths (4)	Excess Deaths (5)	Ratio of Observed to Expected Mortality (6)
October 2017 - March 2018						
Panel A: 65+ Years of Age, High School Dropouts						
Men	1,802	0·121	0·911	1,597	205	1·13
		(-0·110, 0·352)			(37, 373)	(1·01, 1·25)
Women	2,232	0·115	1·168	1,989	243	1·12
		(0·017, 0·214)			(154, 332)	(1·07, 1·17)
Panel B: 65+ Years of Age, High School Graduates						
Men	1,560	0·119	0·591	1,385	175	1·13
		(0·044, 0·195)			(127, 223)	(1·09, 1·17)
Women	1,565	0·012	0·884	1,546	19	1·01
		(-0·033, 0·058)			(-13, 51)	(0·99, 1·03)
Panel C: 65+ Years of Age, Some College or More						
Men	774	0·082	0·7	712·8	61	1·09
		(0·015,0·15)			(39 ,83)	(1·05 ,1·12)
Women	896	0·121	0·929	794·2	102	1·13
		(0·087,0·155)			(89 ,114)	(1·11 ,1·15)

(95% CI 89-114) excess deaths among old age men and women respectively with at least some higher education.

V. Discussion

Our study emphasizes the importance of considerations of displacement in the calculation of post-disaster excess mortality. These displaced populations are frequently overlooked in the context of both disaster relief and the subsequent research, and we argue that ignoring these populations provides an incomplete understanding of the magnitude of the damages and loss of life.

Our empirical framework leverages comparator populations of Cuban and Mexican in the mainland U.S, whose countries of origin were unaffected by Hurricane Maria, but had otherwise similar mortality trends to account for differential mortality among the Puerto Rican population. This methodology is thus applicable both in other countries and in other disaster contexts (both natural and otherwise), particularly as displacement and mobility becomes an increasingly important feature of natural disasters.[17]

While official government estimates of mortality in Puerto Rico were low, reflecting only deaths directly attributable to the Hurricane, excess mortality measures for the six-month period following the disaster were as high as 2,975.[7] Our findings suggest that these measures may be underestimating total excess mortality by an additional 514 deaths (95% CI 346 – 681). In the six months following the passing of Hurricane Maria, we show that individuals of Puerto Rican origin in the mainland U.S saw an increased excess mortality. Crucially, this growth in mortality was concentrated among the most vulnerable populations, with old age adults with lower levels of education seeing the largest increases. These patterns are consistent with excess mortality estimates obtained in Puerto Rico.

Our study is informative regarding the broad mortality consequences of the disaster among the displaced population of Puerto Rico in the U.S. This measure however limits our ability to quantify the elevated burden of disease from morbidity and disability among the displaced population. We were also unable to precisely measure cause-specific mortality causes or the causal pathways for such trends. Given the relatively small numbers of deaths in the population in the period under observation (monthly range 2,119–2,862), informative estimates of more finely defined cause-specific mortality rates were not possible. This remaining important research requires future work.

VI. Conclusion

This analysis suggests the need for not only equitable disaster preparedness, but also the importance of cross-jurisdiction cooperation.[7] These already vulnerable populations may face a number of additional hurdles upon relocation, such as healthcare disruptions and psychological stressors which may exacerbate health impacts of the disaster. Receiving jurisdictions would, thus, benefit from an improved understanding of both the dynamics of post-disaster displacement, and its consequences. Our results may also shed light on the discrepancies between survey-based and other studies using vital records to estimate the Hurricane Maria death toll in Puerto Rico.[10]

Already important efforts exist among jurisdictions in the U.S., such as the State and Territorial Exchange of Vital Events (STEVE) of the National Association for Public Health Statistics Information Systems (NAPHSIS), to facilitate vital records for use by other state-level and territorial public health organizations. However, more coordination is required to speed the flow of data to gain a more comprehensive understanding of the scale of disasters in other countries. Moreover, even among jurisdictions within the U.S., this process can take a considerable amount of time. The speed of flow of vital records depends on the effectiveness of local and county vital registrars to share this information. Ensuring timely exchange of death records among jurisdictions would ensure disaster death toll estimates based on vital records are complete and would hence allow public authorities to have a comprehensive understanding of the scale of the disaster in a timely fashion.

[10] Kishore et al. (2018) surveyed a representative sample of households, asking survivors to account for the whereabouts of all people that lived in their community prior to the Hurricane, irrespective of the location of the occurrence of death of relatives and family members, on the island or elsewhere.[30] As such, we would expect excess mortality estimates based on vital records of the deaths occurring in Puerto Rico to yield lower estimates than a survey-based method that does not restrict death occurrences to Puerto Rico. They found a mortality rate that yielded an estimate of 4,645 excess deaths (95% CI 793-8498) on account of Hurricane Maria. This is notably higher than the estimates prepared using vital records. Our excess mortality estimates of the Puerto Rican 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 the difference in estimates between the survey-based estimate and the estimates based on vital records.

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Supplementary Materials

A. Additional Figures and Tables

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

Paper	Preferred Excess Mortality Estimate
Santos-Lozada A, Howard J.T. (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
Spagat M., van Weezel S. (2020)	910 ± 470

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.[11] 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 (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 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 (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 stimation, 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:

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

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

[11] https://ec.europa.eu/eurostat/cros/content/chow-lin-method-temporal-disaggregation-method_en

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 percent) and of 9·7 percent among women (95% CI 1·04 – 1·17 percent) 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.[12] 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]

[12] These estimates are in line with those in existing studies of population migration from Puerto Rico to the mainland US post-hurricane (e.g., Santos Burgoa et al. 2018; Alexander, Polimis, and Zagheni 2019; DeWaard, Johnson, and Whitaker 2020). Results available upon request from the corresponding author.

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. (4)	Ratio of Observed to Expected Population (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)

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