BMJ Open

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

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2021-058315
Article Type:	Original research
Date Submitted by the Author:	13-Oct-2021
Complete List of Authors:	Marazzi, Mario; Independent Researcher Miloucheva, Boriana; University of Toronto, Department of Economics Bobonis, Gustavo; University of Toronto, Department of Economics
Keywords:	PUBLIC HEALTH, International health services < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, Health & safety < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, Health economics < HEALTH SERVICES ADMINISTRATION & MANAGEMENT

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

Mario Marazzi, PhD[1] , Boriana Miloucheva, M.A[2], and Gustavo Bobonis, Ph.D[3]

[1]*Independent Researcher, San Juan, Puerto Rico, marazzi.m@gmail.com*
[2] *Department of Economics, University of Toronto, and Canadian Centre for Health Economics boriana.miloucheva@mail.utoronto.ca*
[3] *Corresponding author, Department of Economics, University of Toronto, gustavo.bobonis@utoronto.ca*

Manuscript Word Count: 3932

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

Abstract

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

Design: Cross-sectional study

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

Exposures: Hurricane Maria

Main Outcome: We use an interrupted time-series design to analyze all-cause mortality of Puerto Ricans in the U.S. following the Hurricane. 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 origin by age group, gender, and educational attainment.

Results: 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.

Conclusions: 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.

Article Summary

Strengths and limitations

- One of the first studies to examine excess mortality of persons displaced by natural disasters.
- Leverage comparison group mortality outcomes to control for seasonality and period-specific effects, minimizing potential confounding.
- Generate independent estimates of population displacement from the territory to the mainland U.S following Hurricane Maria
- As the mortality outcomes are aggregated at the Hispanic group and gender-age group stratum in each month, we are unable to precisely measure cause-specific mortality.

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.[1] 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.[2]

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.[3] 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.[4] In spite of these methodological limitations, this literature has shaped our understanding of mortality patterns among displaced populations. If conclusions about these forms

---

[1] 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.[18,19]

[2] 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]

[3] 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]

[4] 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.[5] 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.

---

[5] 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.

I. 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.

II. Patient and Public Involvement

No patients involved.

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.[6] 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:

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

---

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

where $I\{g = PR_g\} \cdot I\{t = 1,2,\ldots,6\}$ 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.

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 (-0·110, 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)
Panel B: 65+ Years of Age, High School Graduates						
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)
Panel C: 65+ Years of Age, Some College or More						
Men	774	0·082 (0·015,0·15)	0·7	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)

(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.[7]

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.

[7] 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.

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).

References

1 Iwan WD, Cluff LS, Kimpel JF, *et al.* Mitigation emerges as major strategy for reducing losses caused by natural disasters board on natural disasters. Science. 1999; **284**. DOI:10.1126/science.284.5422.1943.

2 Stocker TF, D. Qin G-K, Plattner MT, *et al.* IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC. 2013.

3 Bourque LB, Siegel JM, Kano M, Wood MM. Weathering the Storm: The Impact of Hurricanes on Physical and Mental Health. *The ANNALS of the American Academy of Political and Social Science* 2006; **604**. DOI:10.1177/0002716205284920.

4 Kousky C. Informing Climate Adaptation: A Review of the Economic Costs of Natural Disasters, Their Determinants, and Risk Reduction Options. *SSRN Electronic Journal* 2012. DOI:10.2139/ssrn.2099769.

5 Galea S, Nandi A, Vlahov D. The epidemiology of post-traumatic stress disorder after disasters. Epidemiologic Reviews. 2005; **27**. DOI:10.1093/epirev/mxi003.

6 Gray C, Frankenberg E, Gillespie T, Sumantri C, Thomas D. Studying Displacement After a Disaster Using Large-Scale Survey Methods: Sumatra After the 2004 Tsunami. *Annals of the Association of American Geographers* 2014; **104**. DOI:10.1080/00045608.2014.892351.

7 Santos-Burgoa C, Sandberg J, Suárez E, *et al.* Differential and persistent risk of excess mortality from Hurricane Maria in Puerto Rico: a time-series analysis. *The Lancet Planetary Health* 2018; **2**. DOI:10.1016/S2542-5196(18)30209-2.

8 Rivera R, Rolke W. Modeling excess deaths after a natural disaster with application to Hurricane Maria. *Statistics in Medicine* 2019; **38**. DOI:10.1002/sim.8314.

9 Santos-Lozada AR, Howard JT. Use of Death Counts from Vital Statistics to Calculate Excess Deaths in Puerto Rico Following Hurricane Maria. JAMA - Journal of the American Medical Association. 2018; **320**. DOI:10.1001/jama.2018.10929.

10 Acosta R, Irizarry R. Post-Hurricane Vital Statistics Expose Fragility of Puerto Rico's Health System. *bioRxiv* 2018. DOI:10.1101/407874.

11 Cruz-Cano R, Mead EL. Causes of excess deaths in Puerto Rico after Hurricane Maria: A time-series estimation. *American Journal of Public Health* 2019; **109**. DOI:10.2105/AJPH.2019.305015.

12 Chow GC, Lin A. Best Linear Unbiased Interpolation, Distribution, and Extrapolation of Time Series by Related Series. *The Review of Economics and Statistics* 1971; **53**. DOI:10.2307/1928739.

13 Santos Silva JMC, Cardoso FN. The Chow-Lin method using dynamic models. *Economic Modelling* 2001; **18**. DOI:10.1016/S0264-9993(00)00039-0.

14 Liang KY, Zeger SL. Longitudinal data analysis using generalized linear models. *Biometrika* 1986; **73**. DOI:10.1093/biomet/73.1.13.

15 Arellano M. Computing Robust Standard Errors for Within-groups Estimators. *Oxford Bulletin of Economics & Statistics* 1987; **49**.

16 White H. Asymptotic Theory for Econometricians. Elsevier, 1984 DOI:10.1016/C2009-0-21869-1.

17 Groen JA, Polivka AE. Hurricane Katrina evacuees: Who they are, where they are, and how they are faring. *Monthly Labor Review* 2008; **131**.

18 Frankenberg E, Laurito MM, Thomas D. Demographic Impact of Disasters. In: International Encyclopedia of the Social & Behavioral Sciences: Second Edition. 2015. DOI:10.1016/B978-0-08-097086-8.31059-5.

19 Uscher-Pines L. Health effects of relocation following disaster: A systematic review of the literature. Disasters. 2009; **33**. DOI:10.1111/j.1467-7717.2008.01059.x.

20 Willoughby M, Kipsaina C, Ferrah N, *et al.* Mortality in Nursing Homes Following Emergency Evacuation: A Systematic Review. Journal of the American Medical Directors Association. 2017; **18**. DOI:10.1016/j.jamda.2017.02.005.

21 Stallings RA. Methodological issues. In: Handbook of disaster research. Springer, 2007: 55–82.

22 Halliday T. Migration, risk, and liquidity constraints in El Salvador. *Economic Development and Cultural Change* 2006; **54**. DOI:10.1086/503584.

23 Frankenberg E, Sumantri C, Thomas D. Effects of a natural disaster on mortality risks over the longer term. *Nature Sustainability* 2020; **3**. DOI:10.1038/s41893-020-0536-3.

24 Jacobsen K, Landau LB. The dual imperative in refugee research: Some methodological and ethical considerations in social science research on forced migration. *Disasters* 2003; **27**. DOI:10.1111/1467-7717.00228.

25 Gray C, Mueller V. Drought and Population Mobility in Rural Ethiopia. *World Development* 2012; **40**. DOI:10.1016/j.worlddev.2011.05.023.

26 Gray CL, Mueller V. Natural disasters and population mobility in Bangladesh. *Proceedings of the National Academy of Sciences of the United States of America* 2012; **109**. DOI:10.1073/pnas.1115944109.

27 Hugo G. Environmental concerns and international migration. *International Migration Review* 1996; **30**. DOI:10.2307/2547462.

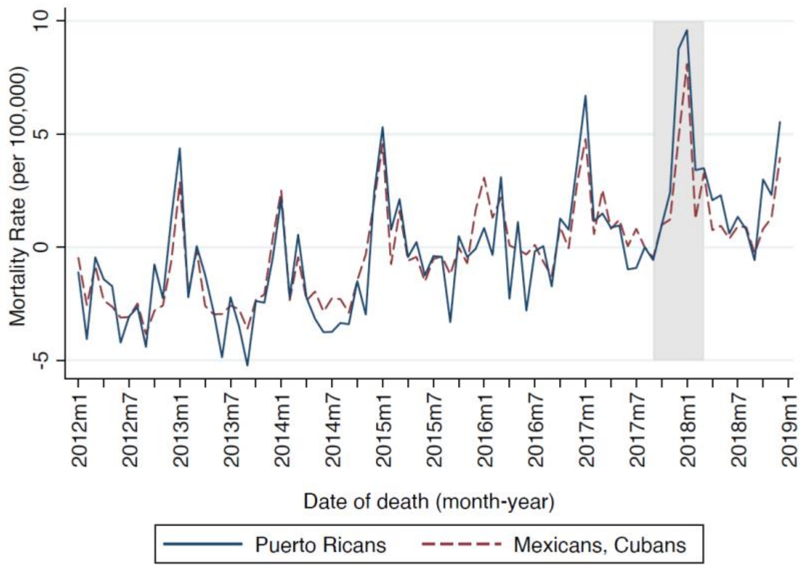
28 Hunter LM. Migration and environmental hazards. Population and Environment. 2005; **26**. DOI:10.1007/s11111-005-3343-x.

29 Naik A. Chapter V: Migration and natural disasters. In: Migration, Environment and Climate Change. 2009.

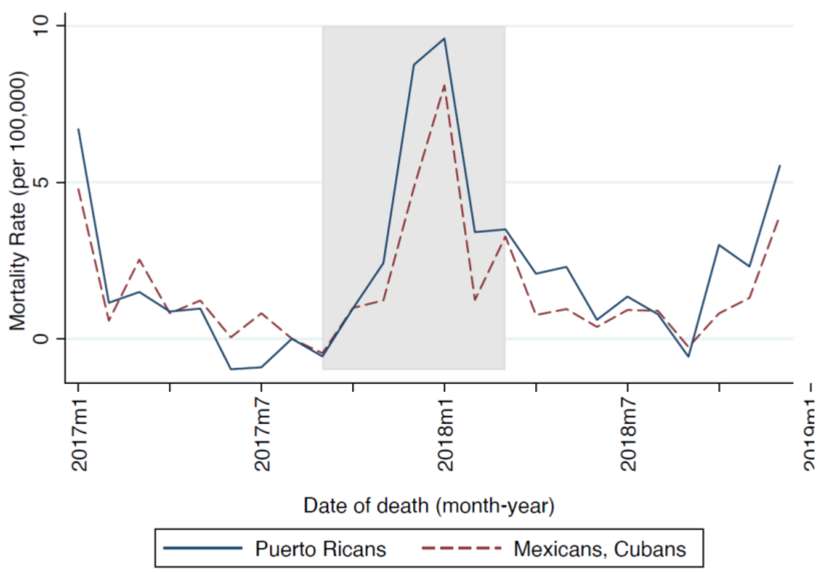
30 Kishore N, Marqués D, Mahmud A, *et al.* Mortality in Puerto Rico after Hurricane Maria. *New England Journal of Medicine* 2018; **379**. DOI:10.1056/nejmsa1803972.

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.

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 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.[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.

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 $exp(ln(\text{Observed Death}_s) - \theta_s)$. 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 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:

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

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

[1] 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.[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]

[2] Results available upon request from 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)

References

1 Santos-Lozada AR, Howard JT. Use of Death Counts from Vital Statistics to Calculate Excess Deaths in Puerto Rico Following Hurricane Maria. JAMA - Journal of the American Medical Association. 2018; **320**. DOI:10.1001/jama.2018.10929.

2 Santos-Burgoa C, Sandberg J, Suárez E, *et al.* Differential and persistent risk of excess mortality from Hurricane Maria in Puerto Rico: a time-series analysis. *The Lancet Planetary Health* 2018; **2**. DOI:10.1016/S2542-5196(18)30209-2.

3 Acosta R, Irizarry R. Post-Hurricane Vital Statistics Expose Fragility of Puerto Rico's Health System. *bioRxiv* 2018. DOI:10.1101/407874.

4 Cruz-Cano R, Mead EL. Causes of excess deaths in Puerto Rico after Hurricane Maria: A time-series estimation. *American Journal of Public Health* 2019; **109**. DOI:10.2105/AJPH.2019.305015.

5 Rivera R, Rolke W. Modeling excess deaths after a natural disaster with application to Hurricane Maria. *Statistics in Medicine* 2019; **38**. DOI:10.1002/sim.8314.

6 Santos Silva JMC, Cardoso FN. The Chow-Lin method using dynamic models. *Economic Modelling* 2001; **18**. DOI:10.1016/S0264-9993(00)00039-0.

7 Chow GC, Lin A. Best Linear Unbiased Interpolation, Distribution, and Extrapolation of Time Series by Related Series. *The Review of Economics and Statistics* 1971; **53**. DOI:10.2307/1928739.

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

	Item No	Recommendation	
Title and abstract	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
Introduction			
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
Methods			
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
Results			
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
Discussion			
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
Other information			
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.

BMJ Open

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

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2021-058315.R1
Article Type:	Original research
Date Submitted by the Author:	14-Feb-2022

Complete List of Authors:	Marazzi, Mario; Independent Researcher Miloucheva, Boriana; University of Toronto, Department of Economics Bobonis, Gustavo; University of Toronto, Department of Economics

Primary Subject Heading:	Public health
Secondary Subject Heading:	Health economics
Keywords:	PUBLIC HEALTH, International health services < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, Health & safety < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, Health economics < HEALTH SERVICES ADMINISTRATION & MANAGEMENT

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

Mario Marazzi, PhD[1] , Boriana Miloucheva, MA[2], and Gustavo Bobonis, Ph.D[3]

[1]*Independent Researcher, San Juan, Puerto Rico, marazzi.m@gmail.com*
[2] *Department of Economics, University of Toronto, and Canadian Centre for Health Economics boriana.miloucheva@mail.utoronto.ca*
[3] *Corresponding author, Department of Economics, University of Toronto, gustavo.bobonis@utoronto.ca*

Manuscript Word Count: 3900

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

Abstract

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

Design: Cross-sectional study

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

Exposures: Hurricane Maria

Main Outcome: We use an interrupted time-series design to analyze all-cause mortality of Puerto Ricans in the U.S. following the Hurricane. 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 origin by age group, gender, and educational attainment.

Results: 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.

Conclusions: 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.

Article Summary

Strengths and limitations

- One of the first studies to examine excess mortality among migrant and displaced populations following a natural disaster.
- Leverage comparison group mortality outcomes to control for seasonality and period-specific effects, minimizing potential confounding.
- As the mortality outcomes are aggregated at the Hispanic group and gender-age group stratum in each month, we are unable to precisely measure cause-specific mortality.
- Our analysis does not allow us to disentangle the excess mortality of displaced populations as opposed to longer-term migrants or second or third-generation individuals of such ancestry.

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.[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.[1] 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.[2]

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.[3] 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.[4] In spite of these methodological limitations, this literature has shaped our understanding of mortality patterns among displaced populations. If conclusions about these forms

[1] 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.[20,21]

[2] 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.[21] Subsequent studies find higher mortality risks for specific displaced subpopulations such as among relocated institutionalized elderly; see Willoughby et al. for a systematic review.[22]

[3] 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.[6,23]

[4] 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.[6,19,20,23–28]

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.[5] Our objective is to estimate 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. 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. To our knowledge, this is the first study to explicitly examine the post-disaster death occurrences of Puerto Ricans in the mainland U.S.

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.

---

[5] We conceptualize post-disaster mobility as a coping strategy that occurs along a spectrum from forced displacement to largely voluntary migration.[6,29–31]

Identifying the existence and magnitude of a period of excess mortality among Puerto Ricans in the United States in the months following the passage of Hurricane Maria over Puerto Rico would support the hypothesis that displaced and migrant populations also face a higher risk of mortality and possibly other health consequences from exposure to such natural disasters.

2. Methods

2.1 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]).

2.2 Patient and Public Involvement

No patients involved.

2.3 Statistical Analysis

Our empirical strategy consists of an interrupted time series / difference-in-differences design. We compare differences in the gender-by-age group stratum 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. We make these comparisons by gender-by-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.

Our estimation procedure uses the observed age-group-by-gender specific deaths that occurred over the period of October 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, between 10,866 and 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).

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 origin averaged 280·89 per 100,000. In contrast, the mortality rate among Cubans and Mexicans throughout this period was 232·17 per 100,000. In spite of this difference in mortality levels, the two groups experienced very similar mortality seasonal patterns and trends 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.[6] 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.

[6] In the Supplemental Appendix, we include a series of placebo tests we performed to evaluate whether there are significant increases in mortality of the Puerto Rican population relative to that of the comparison group pre-October 2017, which confirm the 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)	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)
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, 0·078)			(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	57·830	2,276	9	1·00
		(-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)

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.

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).[7] 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). When examining excess mortality by cause of death among this age group, we estimate these to be concentrated in deaths related to heart diseases, cancer, and diabetes; see Supplementary Materials for details.

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.

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

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 [95% CI] (5)	Ratio of Observed to Expected Mortality [95% CI] (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	2,320	-0·005	7·626	2,332·5	-12	0·99
		(-0·016, 0·005)			(-24, -1)	(0·99, 1·00)
Women	1,276	-0·041	7·967	1,329·1	-53	0·96
		(-0·086, 0·004)			(-80, -26)	(0·94, 0·98)
Panel C: ≥ 65 Years of Age						
Men	4,249	0·073	2·222	3,950·9	298	1·08
		(0·008, 0·137)			(182, 414)	(1·04, 1·11)
Women	4,796	0·064	3·002	4,498·0	298	1·07
		(0·041, 0·088)			(250, 346)	(1·05, 1·08)
Panel D: All						
Men	7,505	0·036	28·630	7,241·0	264	1·04
		(0·022, 0·050)			(162, 366)	(1·02, 1·05)
Women	6,505	0·039	28·604	6,255·0	250	1·04
		(0·028, 0·050)			(179, 320)	(1·03, 1·05)

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 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 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 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.

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 [95% CI] (5)	Ratio of Observed to Expected Mortality [95% CI] (6)
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	0·700	712·8	61	1·09
		(0·015, 0·150)			(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)

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 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 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-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 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.

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

V. Discussion

Main Findings

Our study documents an increase in mortality for persons of Puerto Rican origin in the mainland U.S. during the 6-month period following Hurricane Maria (October 2017 through March 2018). Our findings indicate that measures of excess mortality based on death occurrences in Puerto Rico following the Hurricane may be underestimating total excess mortality by an additional 514 deaths (95% CI 346 – 681) in the six months following the event, partly due to significant displacement of the Puerto Rican population to the mainland U.S. Crucially, this increase 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.[10,11] Analyses of these data also provide a rich description of heterogeneity of the event's impacts to yield generalizable knowledge.

Contribution, Limitations, and Relationship to the Literature

The study contributes to the literature documenting the mortality consequences of Hurricane Maria in Puerto Rico. Several previous attempts to estimate the mortality effects of Hurricane Maria in Puerto Rico, including the official death toll estimate prepared by the Government of Puerto Rico, used Puerto Rico death registrar data and previous years' mortality rate estimates as a benchmark to identify periods of excess mortality in Puerto Rico.[7–11] Preferred mortality estimates for the six and seven-month period following the disaster—which considered only deaths registered in Puerto Rico despite significant population displacement and excluding deaths among the population displaced to the mainland —were as high as 2,975 and 3,400 respectively.[7,10] (We present a summary of the data, techniques, and treatment periods employed in this research in the Online Supplement.) This focus on deaths occurring in the territory resulted in an underestimation of the death toll by approximately 14.7%, which we estimate occurred in the United States. In contrast, Kishore et al. (2018) surveyed a representative sample of households, asking survivors to account for the whereabouts of all people who lived in their community prior to the Hurricane irrespective of the location of the occurrences of death among community members (on the island or elsewhere). Accordingly, they found a mortality rate that yielded an estimate of 4,645 excess deaths (95% CI 793-8,498) on account of Hurricane Maria. Our finding of excess mortality among the population of Puerto Rican origin in the mainland U.S. contributes to explaining the difference in estimates from these two methodological approaches.

An additional contribution of the study is the use of a research design to credibly estimate the excess mortality of displaced and migrant populations during this period while carefully accounting for population displacement following the disaster. Using comparator populations of Cubans and Mexicans in the mainland U.S., our design robustly accounts for different population and mortality trends by age group and gender to account for both displacement and differential mortality among the Puerto Rican population. Our estimates of displacement of the population ages 65 and older of approximately 7.1 percent (40,700 individuals) is in line with the existing literature and supports the consensus using other methodologies that the natural disaster led to displacement in aggregate terms of approximately 4.1-5.6 percent of the total population of Puerto Rico.[17,18] This design, effectively used in related studies and other contexts to account for population movements, is broadly 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.[19]

Our study is informative regarding the broad mortality consequences of the disaster among the displaced and migrant population of Puerto Ricans in the U.S. This measure however limits our ability to quantify the elevated burden of disease from morbidity and disability among this population. We also face some limitations in our ability to precisely estimate cause-specific mortality 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), generating informative estimates of more finely defined cause-specific mortality is not feasible.

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

Policy Implications

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

This analysis suggests the need for not only equitable disaster preparedness, but also the importance of cross-jurisdiction data sharing.[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.

---

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

[9] 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.

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.

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).

Figure 1 Caption:

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.

References

1 Iwan WD, Cluff LS, Kimpel JF, *et al.* Mitigation emerges as major strategy for reducing losses caused by natural disasters board on natural disasters. Science. 1999; **284**. DOI:10.1126/science.284.5422.1943.

2 Stocker TF, D. Qin G-K, Plattner MT, *et al.* IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC. 2013.

3 Bourque LB, Siegel JM, Kano M, Wood MM. Weathering the Storm: The Impact of Hurricanes on Physical and Mental Health. *The ANNALS of the American Academy of Political and Social Science* 2006; **604**. DOI:10.1177/0002716205284920.

4 Kousky C. Informing Climate Adaptation: A Review of the Economic Costs of Natural Disasters, Their Determinants, and Risk Reduction Options. *SSRN Electronic Journal* 2012. DOI:10.2139/ssrn.2099769.

5 Galea S, Nandi A, Vlahov D. The epidemiology of post-traumatic stress disorder after disasters. Epidemiologic Reviews. 2005; **27**. DOI:10.1093/epirev/mxi003.

6 Gray C, Frankenberg E, Gillespie T, Sumantri C, Thomas D. Studying Displacement After a Disaster Using Large-Scale Survey Methods: Sumatra After the 2004 Tsunami. *Annals of the Association of American Geographers* 2014; **104**. DOI:10.1080/00045608.2014.892351.

7 Santos-Burgoa C, Sandberg J, Suárez E, *et al.* Differential and persistent risk of excess mortality from Hurricane Maria in Puerto Rico: a time-series analysis. *The Lancet Planetary Health* 2018; **2**. DOI:10.1016/S2542-5196(18)30209-2.

8 Rivera R, Rolke W. Modeling excess deaths after a natural disaster with application to Hurricane Maria. *Statistics in Medicine* 2019; **38**. DOI:10.1002/sim.8314.

9 Santos-Lozada AR, Howard JT. Use of Death Counts from Vital Statistics to Calculate Excess Deaths in Puerto Rico Following Hurricane Maria. JAMA - Journal of the American Medical Association. 2018; **320**. DOI:10.1001/jama.2018.10929.

10 Acosta R, Irizarry R. Post-Hurricane Vital Statistics Expose Fragility of Puerto Rico's Health System. *bioRxiv* 2018. DOI:10.1101/407874.

11 Cruz-Cano R, Mead EL. Causes of excess deaths in Puerto Rico after Hurricane Maria: A time-series estimation. *American Journal of Public Health* 2019; **109**. DOI:10.2105/AJPH.2019.305015.

12 Chow GC, Lin A. Best Linear Unbiased Interpolation, Distribution, and Extrapolation of Time Series by Related Series. *The Review of Economics and Statistics* 1971; **53**. DOI:10.2307/1928739.

13 Santos Silva JMC, Cardoso FN. The Chow-Lin method using dynamic models. *Economic Modelling* 2001; **18**. DOI:10.1016/S0264-9993(00)00039-0.

14 Liang KY, Zeger SL. Longitudinal data analysis using generalized linear models. *Biometrika* 1986; **73**. DOI:10.1093/biomet/73.1.13.

15 Arellano M. Computing Robust Standard Errors for Within-groups Estimators. *Oxford Bulletin of Economics & Statistics* 1987; **49**.

16 White H. Asymptotic Theory for Econometricians. Elsevier, 1984 DOI:10.1016/C2009-0-21869-1.

17 Acosta RJ, Kishore N, Irizarry RA, Buckee CO. Quantifying the dynamics of migration after Hurricane Maria in Puerto Rico. *Proceedings of the National Academy of Sciences of the United States of America* 2020; **117**. DOI:10.1073/pnas.2001671117.

18 Alexander M, Polimis K, Zagheni E. The Impact of Hurricane Maria on Out-migration from Puerto Rico: Evidence from Facebook Data. *Population and Development Review* 2019; **45**. DOI:10.1111/padr.12289.

19 Groen JA, Polivka AE. Hurricane Katrina evacuees: Who they are, where they are, and how they are faring. *Monthly Labor Review* 2008; **131**.

20 Frankenberg E, Laurito MM, Thomas D. Demographic Impact of Disasters. In: International Encyclopedia of the Social & Behavioral Sciences: Second Edition. 2015. DOI:10.1016/B978-0-08-097086-8.31059-5.

21 Uscher-Pines L. Health effects of relocation following disaster: A systematic review of the literature. Disasters. 2009; **33**. DOI:10.1111/j.1467-7717.2008.01059.x.

22 Willoughby M, Kipsaina C, Ferrah N, *et al.* Mortality in Nursing Homes Following Emergency Evacuation: A Systematic Review. Journal of the American Medical Directors Association. 2017; **18**. DOI:10.1016/j.jamda.2017.02.005.

23 Stallings RA. Methodological issues. In: Handbook of disaster research. Springer, 2007: 55–82.

24 Halliday T. Migration, risk, and liquidity constraints in El Salvador. *Economic Development and Cultural Change* 2006; **54**. DOI:10.1086/503584.

25 Frankenberg E, Sumantri C, Thomas D. Effects of a natural disaster on mortality risks over the longer term. *Nature Sustainability* 2020; **3**. DOI:10.1038/s41893-020-0536-3.

26 Jacobsen K, Landau LB. The dual imperative in refugee research: Some methodological and ethical considerations in social science research on forced migration. *Disasters* 2003; **27**. DOI:10.1111/1467-7717.00228.

27 Gray C, Mueller V. Drought and Population Mobility in Rural Ethiopia. *World Development* 2012; **40**. DOI:10.1016/j.worlddev.2011.05.023.

28 Gray CL, Mueller V. Natural disasters and population mobility in Bangladesh. *Proceedings of the National Academy of Sciences of the United States of America* 2012; **109**. DOI:10.1073/pnas.1115944109.

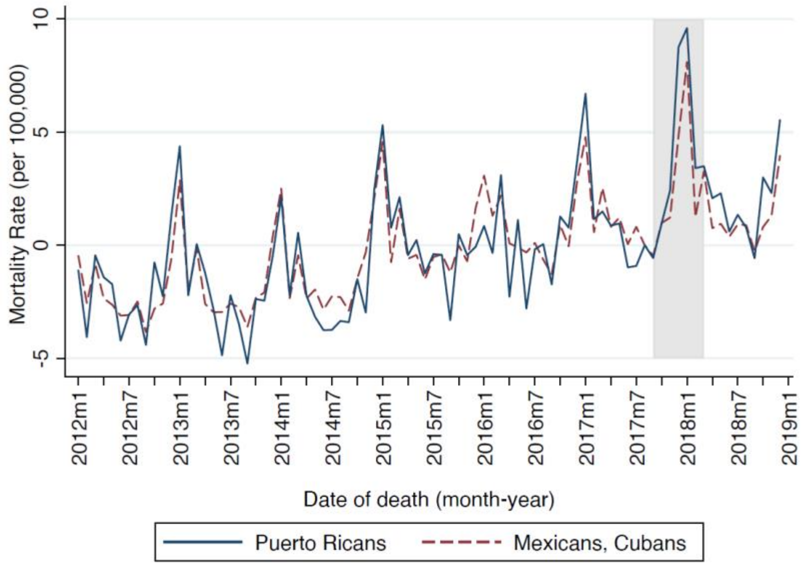
29 Hugo G. Environmental concerns and international migration. *International Migration Review* 1996; **30**. DOI:10.2307/2547462.

30 Hunter LM. Migration and environmental hazards. Population and Environment. 2005; **26**. DOI:10.1007/s11111-005-3343-x.

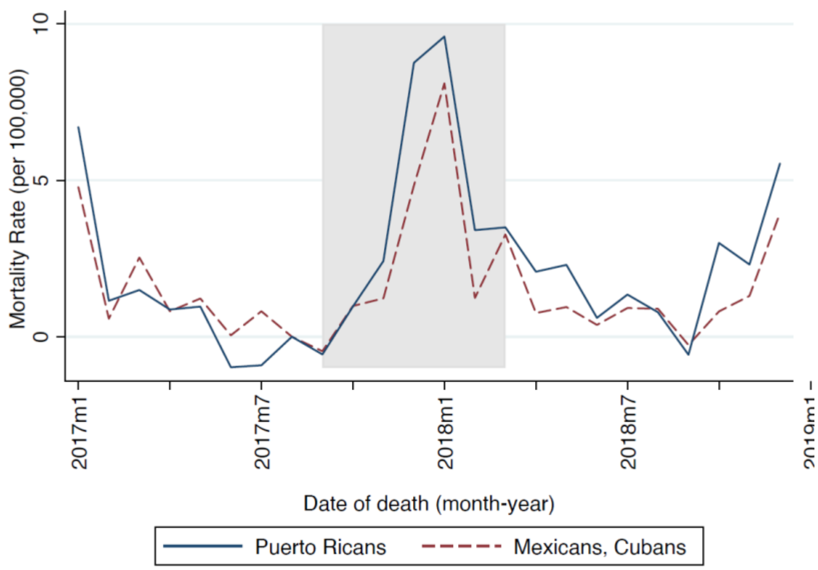
31 Naik A. Chapter V: Migration and natural disasters. In: Migration, Environment and Climate Change. 2009.

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.

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*(Observed Deaths$_s$) - θ_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.

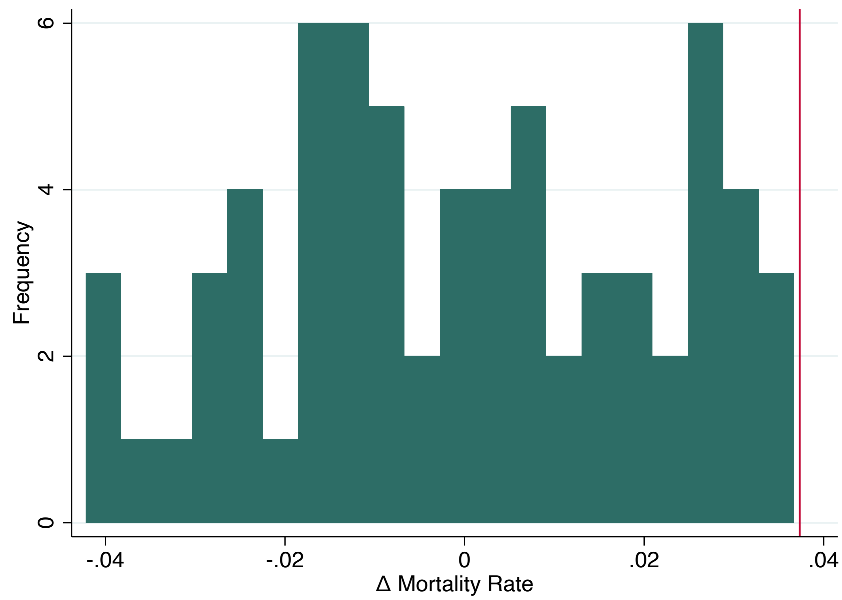
Table B.2: Excess Mortality of the Puerto Rican Population in the Mainland US by Cause of Death, Overall and Old-Age Population (October 2017 – March 2018)

	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 (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.

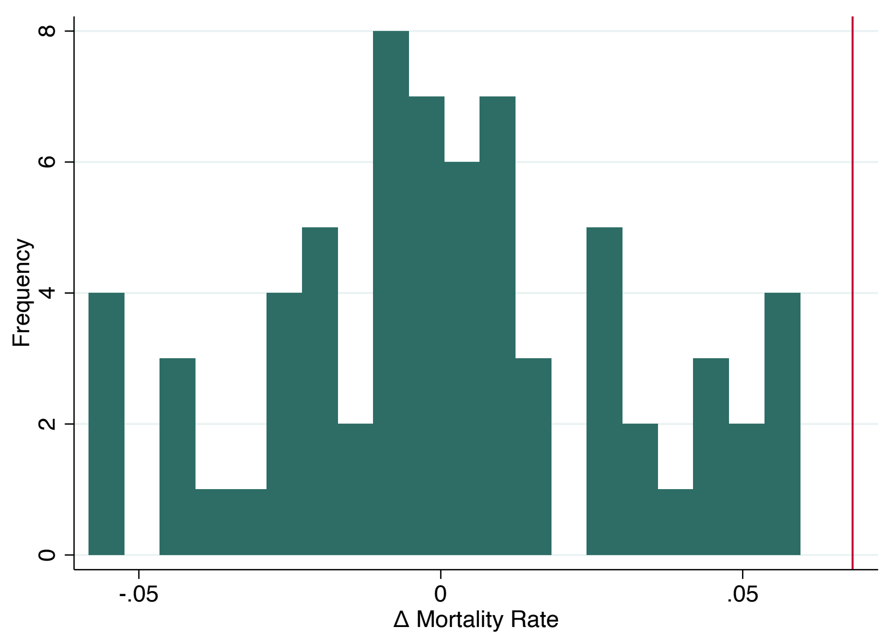
Figure B.1: Distribution of Placebo Tests for Evaluation of Differences-in-Differences Research Design

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).

References

1 Santos-Lozada AR, Howard JT. Use of Death Counts from Vital Statistics to Calculate Excess Deaths in Puerto Rico Following Hurricane Maria. JAMA - Journal of the American Medical Association. 2018; **320**. DOI:10.1001/jama.2018.10929.

2 Santos-Burgoa C, Sandberg J, Suárez E, *et al.* Differential and persistent risk of excess mortality from Hurricane Maria in Puerto Rico: a time-series analysis. *The Lancet Planetary Health* 2018; **2**. DOI:10.1016/S2542-5196(18)30209-2.

3 Acosta R, Irizarry R. Post-Hurricane Vital Statistics Expose Fragility of Puerto Rico's Health System. *bioRxiv* 2018. DOI:10.1101/407874.

4 Cruz-Cano R, Mead EL. Causes of excess deaths in Puerto Rico after Hurricane Maria: A time-series estimation. *American Journal of Public Health* 2019; **109**. DOI:10.2105/AJPH.2019.305015.

5 Rivera R, Rolke W. Modeling excess deaths after a natural disaster with application to Hurricane Maria. *Statistics in Medicine* 2019; **38**. DOI:10.1002/sim.8314.

6 Santos Silva JMC, Cardoso FN. The Chow-Lin method using dynamic models. *Economic Modelling* 2001; **18**. DOI:10.1016/S0264-9993(00)00039-0.

7 Chow GC, Lin A. Best Linear Unbiased Interpolation, Distribution, and Extrapolation of Time Series by Related Series. *The Review of Economics and Statistics* 1971; **53**. DOI:10.2307/1928739.

8 Alexander M, Polimis K, Zagheni E. The Impact of Hurricane Maria on Out-migration from Puerto Rico: Evidence from Facebook Data. *Population and Development Review* 2019; **45**. DOI:10.1111/padr.12289.

9 Acosta RJ, Kishore N, Irizarry RA, Buckee CO. Quantifying the dynamics of migration after Hurricane Maria in Puerto Rico. *Proceedings of the National Academy of Sciences of the United States of America* 2020; **117**. DOI:10.1073/pnas.2001671117.

10 Meléndez, Edwin and Hinojosa J. Estimates of Post-Hurricane Maria Exodus from Puerto Rico. *Centro Voices* 2017.

11 Echenique M, Melgar L. Mapping Puerto Rico's Hurricane Migration with Mobile Phone Data. City Lab. https://www.citylab.com/ environment/2018/05/watch-puerto-ricos-hurricane-migration-via-mobile-phone-data/ 559889/ (accessed Feb 3, 2022).

12 Stefan Rayer. Estimating the Migration of Puerto Ricans to Florida Using Flight Passenger Data. 2018 https://www.bebr.ufl.edu/sites/default/files/Research%20Reports/puerto_rican_migration.pdf. (accessed Feb 2, 2022).

13 Santos-Lozada AR. Estimates of Excess Passenger Traffic in Puerto Rico following Hurricane María. 2018 https://osf.io/ jhkyv/download/?format=pdf (accessed Feb 2, 2022).

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

	Item No	Recommendation	
Title and abstract	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
Introduction			
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
Methods			
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
Results			
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
Discussion			
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
Other information			
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.

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

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2021-058315.R2
Article Type:	Original research
Date Submitted by the Author:	22-Mar-2022
Complete List of Authors:	Marazzi, Mario; Independent Researcher Miloucheva, Boriana; University of Toronto, Department of Economics Bobonis, Gustavo; University of Toronto, Department of Economics
Primary Subject Heading:	Public health
Secondary Subject Heading:	Health economics
Keywords:	PUBLIC HEALTH, International health services < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, Health & safety < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, Health economics < HEALTH SERVICES ADMINISTRATION & MANAGEMENT

SCHOLARONE™ Manuscripts

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

Mario Marazzi, PhD[1] , Boriana Miloucheva, MA[2], and Gustavo Bobonis, Ph.D[3]

[1]*Independent Researcher, San Juan, Puerto Rico, marazzi.m@gmail.com*
[2] *Department of Economics, University of Toronto, and Canadian Centre for Health Economics boriana.miloucheva@mail.utoronto.ca*
[3] *Corresponding author, Department of Economics, University of Toronto, gustavo.bobonis@utoronto.ca*

Manuscript Word Count: 3962

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

Abstract

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

Design: Cross-sectional study

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

Exposures: Hurricane Maria

Main Outcome: We use an interrupted time-series design to analyze all-cause mortality of Puerto Ricans in the U.S. following the Hurricane. 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 origin by age group, gender, and educational attainment.

Results: 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.

Conclusions: 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.

Article Summary

Strengths and limitations

- One of the first studies to examine excess mortality among migrant and displaced populations following a natural disaster.
- Leverage comparison group mortality outcomes to control for seasonality and period-specific effects, minimizing potential confounding.
- As the mortality outcomes are aggregated at the Hispanic group and gender-age group stratum in each month, we are unable to precisely measure cause-specific mortality.
- Our analysis does not allow us to disentangle the excess mortality of displaced populations as opposed to longer-term migrants or second or third-generation individuals of such ancestry.

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.[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.[1] 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.[2]

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.[3] 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.[4] In spite of these methodological limitations, this literature has shaped our understanding of mortality patterns among displaced populations. If conclusions about these forms

---

[1] 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.[7,8]

[2] 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.[8] Subsequent studies find higher mortality risks for specific displaced subpopulations such as among relocated institutionalized elderly; see Willoughby et al. for a systematic review.[9]

[3] 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.[6,10]

[4] 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.[6,7,10–16]

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.[5] Our objective is to estimate 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. 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).[17–21] 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. To our knowledge, this is the first study to explicitly examine the post-disaster death occurrences of Puerto Ricans in the mainland U.S.

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.

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

Identifying the existence and magnitude of a period of excess mortality among Puerto Ricans in the United States in the months following the passage of Hurricane Maria over Puerto Rico would support the hypothesis that displaced and migrant populations also face a higher risk of mortality and possibly other health consequences from exposure to such natural disasters.

2. Methods

2.1 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.[25] 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.[26] 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.[27,28] 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]).

2.2 Patient and Public Involvement

No patients involved.

2.3 Statistical Analysis

Our empirical strategy consists of an interrupted time series / difference-in-differences design. We compare differences in the gender-by-age group stratum 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. We make these comparisons by gender-by-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.[29–31] 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:

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

where $\mathrm{I}\{g = \mathrm{PR_g}\} \cdot \mathrm{I}\{t = 1,2,\ldots,6\}$ 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.

Our estimation procedure uses the observed age-group-by-gender specific deaths that occurred over the period of October 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, between 10,866 and 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).

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 origin averaged 280·89 per 100,000. In contrast, the mortality rate among Cubans and Mexicans throughout this period was 232·17 per 100,000. In spite of this difference in mortality levels, the two groups experienced very similar mortality seasonal patterns and trends 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.[6] 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.

[6] In the Supplemental Appendix, we include a series of placebo tests we performed to evaluate whether there are significant increases in mortality of the Puerto Rican population relative to that of the comparison group pre-October 2017, which confirm the 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)	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)
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, 0·078)			(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	57·830	2,276	9	1·00
		(-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)

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.

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).[7] 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). When examining excess mortality by cause of death among this age group, we estimate these to be concentrated in deaths related to heart diseases, cancer, and diabetes; see Supplementary Materials for details.

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.

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

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 [95% CI] (5)	Ratio of Observed to Expected Mortality [95% CI] (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	2,320	-0·005	7·626	2,332·5	-12	0·99
		(-0·016, 0·005)			(-24, -1)	(0·99, 1·00)
Women	1,276	-0·041	7·967	1,329·1	-53	0·96
		(-0·086, 0·004)			(-80, -26)	(0·94, 0·98)
Panel C: ≥ 65 Years of Age						
Men	4,249	0·073	2·222	3,950·9	298	1·08
		(0·008, 0·137)			(182, 414)	(1·04, 1·11)
Women	4,796	0·064	3·002	4,498·0	298	1·07
		(0·041, 0·088)			(250, 346)	(1·05, 1·08)
Panel D: All						
Men	7,505	0·036	28·630	7,241·0	264	1·04
		(0·022, 0·050)			(162, 366)	(1·02, 1·05)
Women	6,505	0·039	28·604	6,255·0	250	1·04
		(0·028, 0·050)			(179, 320)	(1·03, 1·05)

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 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 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 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.

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 [95% CI] (5)	Ratio of Observed to Expected Mortality [95% CI] (6)
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	0·700	712·8	61	1·09
		(0·015, 0·150)			(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)

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 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 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-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 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.

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 (95% CI 89-114) excess deaths among old age men and women respectively with at least some higher education.[8]

V. Discussion

Main Findings

Our study documents an increase in mortality for persons of Puerto Rican origin in the mainland U.S. during the 6-month period following Hurricane Maria (October 2017 through March 2018). Our findings indicate that measures of excess mortality based on death occurrences in Puerto Rico following the Hurricane may be underestimating total excess mortality by an additional 514 deaths (95% CI 346 – 681) in the six months following the event, partly due to significant displacement of the Puerto Rican population to the mainland U.S. Crucially, this increase 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.[20,21] Analyses of these data also provide a rich description of heterogeneity of the event's impacts to yield generalizable knowledge.

Contribution, Limitations, and Relationship to the Literature

The study contributes to the literature documenting the mortality consequences of Hurricane Maria in Puerto Rico. Several previous attempts to estimate the mortality effects of Hurricane Maria in Puerto Rico, including the official death toll estimate prepared by the Government of Puerto Rico, used Puerto Rico death registrar data and previous years' mortality rate estimates as a benchmark to identify periods of excess mortality in Puerto Rico.[17–21] Preferred mortality estimates for the six and seven-month period following the disaster—which considered only deaths registered in Puerto Rico despite significant population displacement and excluding deaths among the population

[8] We exclude deaths and population counts with missing educational attainment data from this particular analysis. Accordingly, excess mortality estimates for the group of individuals aged 65+ in Table 3 do not sum to the estimates reported in Panel C of Table 2. Nevertheless, given the level of precision of our estimates we cannot reject that these are in the same range.

displaced to the mainland —were as high as 2,975 and 3,400 respectively.[17,20] (We present a summary of the data, techniques, and treatment periods employed in this research in the Online Supplement.) This focus on deaths occurring in the territory resulted in an underestimation of the death toll by approximately 14.7%, which we estimate occurred in the United States. In contrast, Kishore et al. (2018) surveyed a representative sample of households, asking survivors to account for the whereabouts of all people who lived in their community prior to the Hurricane irrespective of the location of the occurrences of death among community members (on the island or elsewhere). Accordingly, they found a mortality rate that yielded an estimate of 4,645 excess deaths (95% CI 793-8,498) on account of Hurricane Maria. Our finding of excess mortality among the population of Puerto Rican origin in the mainland U.S. contributes to explaining the difference in estimates from these two methodological approaches.

An additional contribution of the study is the use of a research design to credibly estimate the excess mortality of displaced and migrant populations during this period while carefully accounting for population displacement following the disaster. Using comparator populations of Cubans and Mexicans in the mainland U.S., our design robustly accounts for different population and mortality trends by age group and gender to account for both displacement and differential mortality among the Puerto Rican population. Our estimates of displacement of the population ages 65 and older of approximately 7.1 percent (40,700 individuals) is in line with the existing literature and supports the consensus using other methodologies that the natural disaster led to displacement in aggregate terms of approximately 4.1-5.6 percent of the total population of Puerto Rico.[32,33] This design, effectively used in related studies and other contexts to account for population movements, is broadly 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.[11]

Our study is informative regarding the broad mortality consequences of the disaster among the displaced and migrant population of Puerto Ricans in the U.S. This measure however limits our ability to quantify the elevated burden of disease from morbidity and disability among this population. We also face some limitations in our ability to precisely estimate cause-specific mortality 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), generating informative estimates of more finely defined cause-specific mortality is not feasible.

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

Policy Implications

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

This analysis suggests the need for not only equitable disaster preparedness, but also the importance of cross-jurisdiction data sharing.[17] These already vulnerable populations may face a number of additional hurdles upon relocation, such as healthcare disruptions and psychological

[9] Our estimate also excludes persons exposed to the Hurricane, who may have been displaced to other countries, most notably the neighboring Dominican Republic.

[10] 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.

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.

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.

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).

Figure 1 Caption:

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.

References

1 Iwan WD, Cluff LS, Kimpel JF, *et al.* Mitigation emerges as major strategy for reducing losses caused by natural disasters board on natural disasters. Science (1979). 1999; **284**. DOI:10.1126/science.284.5422.1943.

2 Stocker TF, D. Qin G-K, Plattner MT, *et al.* IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC. 2013.

3 Bourque LB, Siegel JM, Kano M, Wood MM. Weathering the Storm: The Impact of Hurricanes on Physical and Mental Health. *The ANNALS of the American Academy of Political and Social Science* 2006; **604**. DOI:10.1177/0002716205284920.

4 Kousky C. Informing Climate Adaptation: A Review of the Economic Costs of Natural Disasters, Their Determinants, and Risk Reduction Options. *SSRN Electronic Journal* 2012. DOI:10.2139/ssrn.2099769.

5 Galea S, Nandi A, Vlahov D. The epidemiology of post-traumatic stress disorder after disasters. Epidemiologic Reviews. 2005; **27**. DOI:10.1093/epirev/mxi003.

6 Gray C, Frankenberg E, Gillespie T, Sumantri C, Thomas D. Studying Displacement After a Disaster Using Large-Scale Survey Methods: Sumatra After the 2004 Tsunami. *Annals of the Association of American Geographers* 2014; **104**. DOI:10.1080/00045608.2014.892351.

7 Frankenberg E, Laurito MM, Thomas D. Demographic Impact of Disasters. In: International Encyclopedia of the Social & Behavioral Sciences: Second Edition. 2015. DOI:10.1016/B978-0-08-097086-8.31059-5.

8 Uscher-Pines L. Health effects of relocation following disaster: A systematic review of the literature. Disasters. 2009; **33**. DOI:10.1111/j.1467-7717.2008.01059.x.

9 Willoughby M, Kipsaina C, Ferrah N, *et al.* Mortality in Nursing Homes Following Emergency Evacuation: A Systematic Review. J Am Med Dir Assoc. 2017; **18**. DOI:10.1016/j.jamda.2017.02.005.

10 Stallings RA. Methodological issues. In: Handbook of disaster research. Springer, 2007: 55–82.

11 Groen JA, Polivka AE. Hurricane Katrina evacuees: Who they are, where they are, and how they are faring. *Monthly Labor Review* 2008; **131**.

12 Halliday T. Migration, risk, and liquidity constraints in El Salvador. *Economic Development and Cultural Change* 2006; **54**. DOI:10.1086/503584.

13 Frankenberg E, Sumantri C, Thomas D. Effects of a natural disaster on mortality risks over the longer term. *Nature Sustainability* 2020; **3**. DOI:10.1038/s41893-020-0536-3.

14 Jacobsen K, Landau LB. The dual imperative in refugee research: Some methodological and ethical considerations in social science research on forced migration. *Disasters* 2003; **27**. DOI:10.1111/1467-7717.00228.

15 Gray C, Mueller V. Drought and Population Mobility in Rural Ethiopia. *World Development* 2012; **40**. DOI:10.1016/j.worlddev.2011.05.023.

16 Gray CL, Mueller V. Natural disasters and population mobility in Bangladesh. *Proc Natl Acad Sci U S A* 2012; **109**. DOI:10.1073/pnas.1115944109.

17 Santos-Burgoa C, Sandberg J, Suárez E, *et al.* Differential and persistent risk of excess mortality from Hurricane Maria in Puerto Rico: a time-series analysis. *The Lancet Planetary Health* 2018; **2**. DOI:10.1016/S2542-5196(18)30209-2.

18 Rivera R, Rolke W. Modeling excess deaths after a natural disaster with application to Hurricane Maria. *Statistics in Medicine* 2019; **38**. DOI:10.1002/sim.8314.

19 Santos-Lozada AR, Howard JT. Use of Death Counts from Vital Statistics to Calculate Excess Deaths in Puerto Rico Following Hurricane Maria. JAMA - Journal of the American Medical Association. 2018; **320**. DOI:10.1001/jama.2018.10929.

20 Acosta R, Irizarry R. Post-Hurricane Vital Statistics Expose Fragility of Puerto Rico's Health System. *bioRxiv* 2018. DOI:10.1101/407874.

21 Cruz-Cano R, Mead EL. Causes of excess deaths in Puerto Rico after Hurricane Maria: A time-series estimation. *American Journal of Public Health* 2019; **109**. DOI:10.2105/AJPH.2019.305015.

22 Hugo G. Environmental concerns and international migration. *International Migration Review* 1996; **30**. DOI:10.2307/2547462.

23 Hunter LM. Migration and environmental hazards. Population and Environment. 2005; **26**. DOI:10.1007/s11111-005-3343-x.

24 Naik A. Chapter V: Migration and natural disasters. In: Migration, Environment and Climate Change. 2009.

25 **[Dataset]** U.S. Centers for Disease Control and Prevention, National Center for Health Statistics. Mortality Multiple Cause Files, 2012-2018. https://www.cdc.gov/nchs/nvss/mortality_public_use_data.htm.

26 **[Dataset]** United States Census Bureau. American Community Survey. https://www2.census.gov/programs-surveys/acs/data/pums/.

27 Chow GC, Lin A. Best Linear Unbiased Interpolation, Distribution, and Extrapolation of Time Series by Related Series. *The Review of Economics and Statistics* 1971; **53**. DOI:10.2307/1928739.

28 Santos Silva JMC, Cardoso FN. The Chow-Lin method using dynamic models. *Economic Modelling* 2001; **18**. DOI:10.1016/S0264-9993(00)00039-0.

29 Liang KY, Zeger SL. Longitudinal data analysis using generalized linear models. *Biometrika* 1986; **73**. DOI:10.1093/biomet/73.1.13.

30 Arellano M. Computing Robust Standard Errors for Within-groups Estimators. *Oxford Bulletin of Economics & Statistics* 1987; **49**.

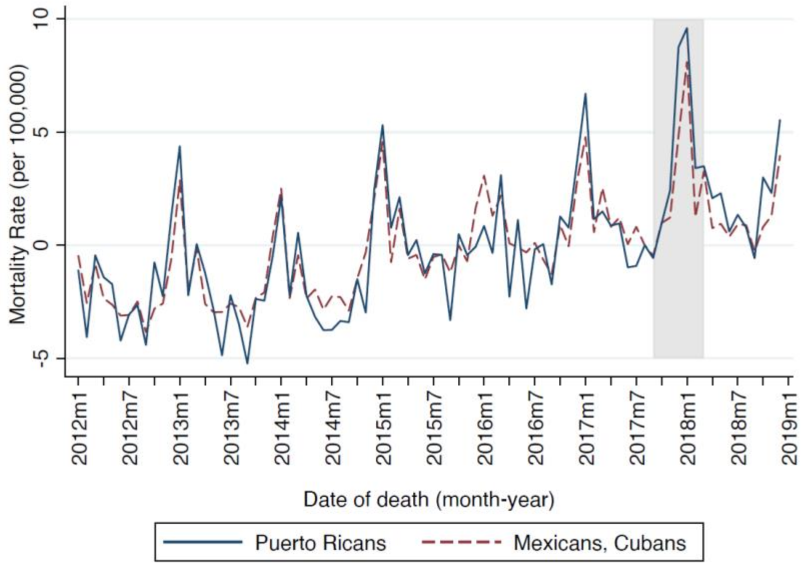
31 White H. Asymptotic Theory for Econometricians. Elsevier, 1984 DOI:10.1016/C2009-0-21869-1.

32 Acosta RJ, Kishore N, Irizarry RA, Buckee CO. Quantifying the dynamics of migration after Hurricane Maria in Puerto Rico. *Proc Natl Acad Sci U S A* 2020; **117**. DOI:10.1073/pnas.2001671117.

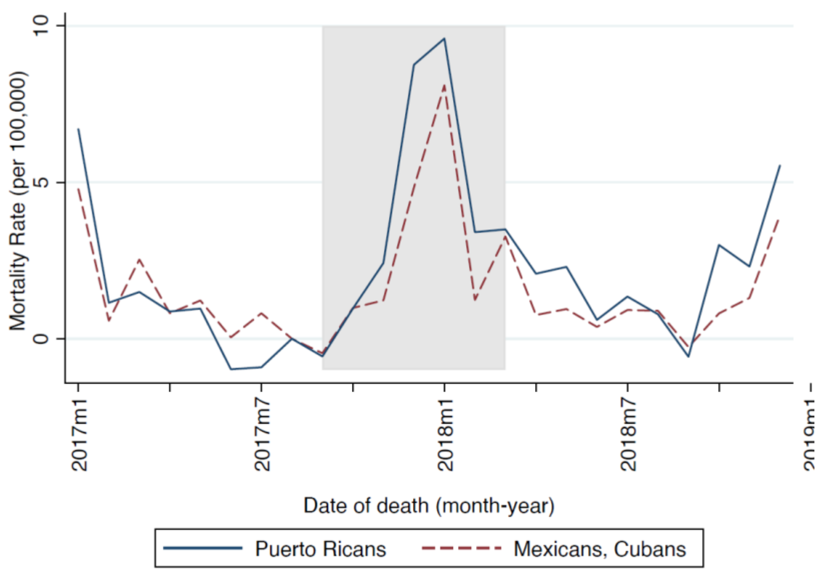
33 Alexander M, Polimis K, Zagheni E. The Impact of Hurricane Maria on Out-migration from Puerto Rico: Evidence from Facebook Data. *Population and Development Review* 2019; **45**. DOI:10.1111/padr.12289.

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



<u>Notes</u>: 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[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 $exp(ln(\text{Observed Deaths}_s) - \theta_s)$. 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 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.

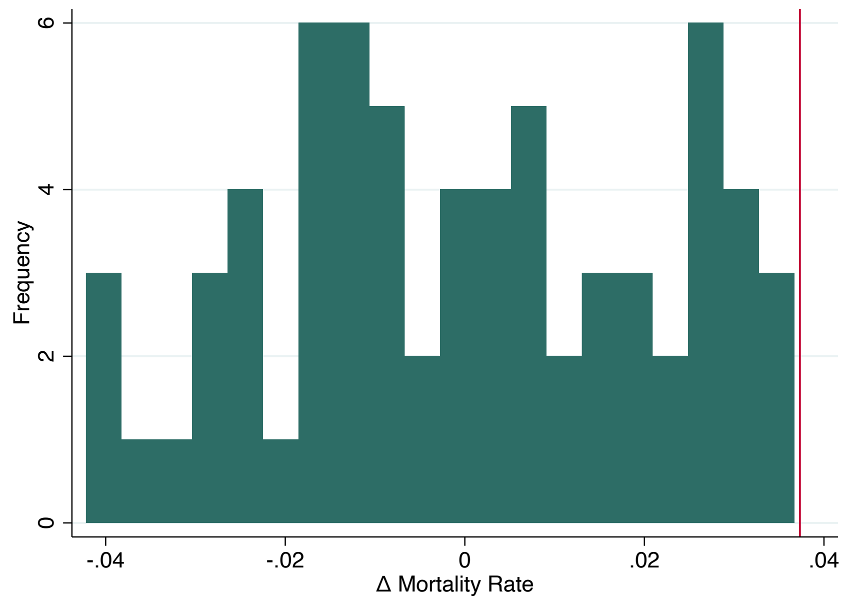
Table B.2: Excess Mortality of the Puerto Rican Population in the Mainland US by Cause of Death, Overall and Old-Age Population (October 2017 – March 2018)

	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 (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.

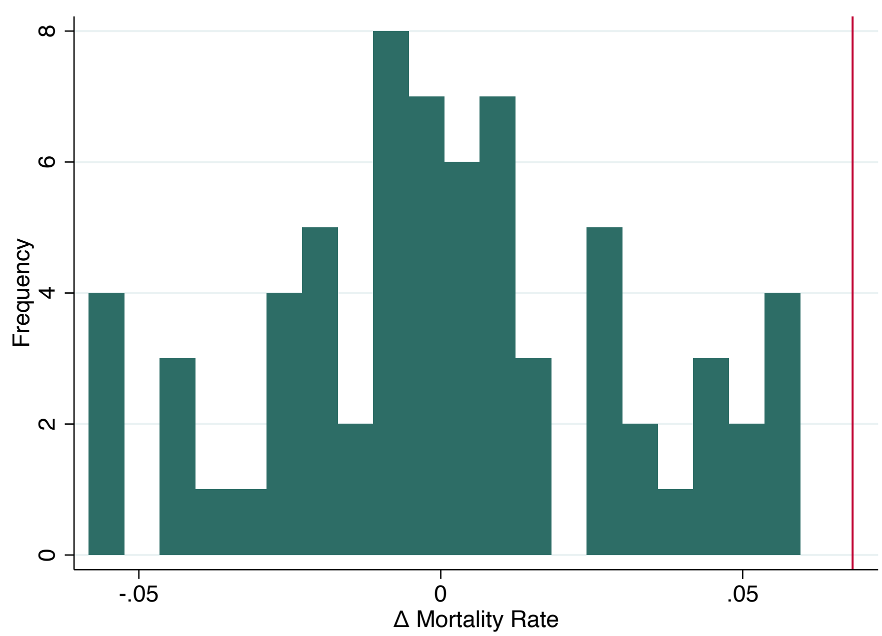
Figure B.1: Distribution of Placebo Tests for Evaluation of Differences-in-Differences Research Design

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).

References

1 Santos-Lozada AR, Howard JT. Use of Death Counts from Vital Statistics to Calculate Excess Deaths in Puerto Rico Following Hurricane Maria. JAMA - Journal of the American Medical Association. 2018; **320**. DOI:10.1001/jama.2018.10929.

2 Santos-Burgoa C, Sandberg J, Suárez E, *et al.* Differential and persistent risk of excess mortality from Hurricane Maria in Puerto Rico: a time-series analysis. *The Lancet Planetary Health* 2018; **2**. DOI:10.1016/S2542-5196(18)30209-2.

3 Acosta R, Irizarry R. Post-Hurricane Vital Statistics Expose Fragility of Puerto Rico's Health System. *bioRxiv* 2018. DOI:10.1101/407874.

4 Cruz-Cano R, Mead EL. Causes of excess deaths in Puerto Rico after Hurricane Maria: A time-series estimation. *American Journal of Public Health* 2019; **109**. DOI:10.2105/AJPH.2019.305015.

5 Rivera R, Rolke W. Modeling excess deaths after a natural disaster with application to Hurricane Maria. *Statistics in Medicine* 2019; **38**. DOI:10.1002/sim.8314.

6 Santos Silva JMC, Cardoso FN. The Chow-Lin method using dynamic models. *Economic Modelling* 2001; **18**. DOI:10.1016/S0264-9993(00)00039-0.

7 Chow GC, Lin A. Best Linear Unbiased Interpolation, Distribution, and Extrapolation of Time Series by Related Series. *The Review of Economics and Statistics* 1971; **53**. DOI:10.2307/1928739.

8 Alexander M, Polimis K, Zagheni E. The Impact of Hurricane Maria on Out-migration from Puerto Rico: Evidence from Facebook Data. *Population and Development Review* 2019; **45**. DOI:10.1111/padr.12289.

9 Acosta RJ, Kishore N, Irizarry RA, Buckee CO. Quantifying the dynamics of migration after Hurricane Maria in Puerto Rico. *Proceedings of the National Academy of Sciences of the United States of America* 2020; **117**. DOI:10.1073/pnas.2001671117.

10 Meléndez, Edwin and Hinojosa J. Estimates of Post-Hurricane Maria Exodus from Puerto Rico. *Centro Voices* 2017.

11 Echenique M, Melgar L. Mapping Puerto Rico's Hurricane Migration with Mobile Phone Data. City Lab. https://www.citylab.com/ environment/2018/05/watch-puerto-ricos-hurricane-migration-via-mobile-phone-data/ 559889/ (accessed Feb 3, 2022).

12 Stefan Rayer. Estimating the Migration of Puerto Ricans to Florida Using Flight Passenger Data. 2018 https://www.bebr. ufl.edu/sites/default/files/Research%20Reports/puerto_rican_migration.pdf. (accessed Feb 2, 2022).

13 Santos-Lozada AR. Estimates of Excess Passenger Traffic in Puerto Rico following Hurricane María. 2018 https://osf.io/ jhkyv/download/?format=pdf (accessed Feb 2, 2022).

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

	Item No	Recommendation	
Title and abstract	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
Introduction			
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
Methods			
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
Results			
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
Discussion			
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
Other information			
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.