

Revisiting the Demography of Disaster: Population Estimates After Hurricane Maria

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Abstract

Hurricane María made landfall in Puerto Rico, in September 2017, causing economic damages and affecting the population by increasing temporarily increasing mortality and outgoing passenger flow. Because of the disruption in the migration flows, the volatility of this time series we must approach the production of population estimates, projections and forecasts carefully. Given that population estimates have been difficult to produce for Puerto Rico before Hurricane Maria and even more challenging following this disaster, this paper proposes an application of the demographic balancing equation using administrative records to produce population estimates on a monthly basis for Puerto Rico. A combination of data from: (1) monthly counts for deaths and births obtained from the Puerto Rico Vital Statistics Systems, (2) passenger flow data produced by the U.S. Bureau of Transportation Statistics, and (3) baseline census counts. I employ this approach to produce monthly estimates of the population for Puerto Rico, and use 2010 Census counts to assess the accuracy of the model. According to the 2010 decennial census, the population of Puerto Rico was 3,725,789 people; by employing the demographic balancing equation approach, the population was estimated to be 3,669,676 people in April 1, 2010. Using this model, I find that after Hurricane Maria, the population of Puerto Rico reached less than 3 million persons in December 2017 (2.97 million). The total population went back to over 3.0 million by January 2018 with an estimated population of 3.02 million people on September 2018.

Introduction

In the early morning of September 20 2017, hurricane Maria, a category 4 hurricane with winds of 155 mph (250 km/h), made landfall near Yabucoa, Puerto Rico. In Puerto Rico, the hurricane caused \$102 billion worth of damage and caused the death of more than 1,000 persons (Central Office for Recovery Reconstruction and Resiliency, 2018; Sandberg et al., 2019). In addition, it was speculated that Hurricane Maria and its aftermath would accelerate the migration from Puerto Rico, an place that has been struggling with population decline since 2005 (Hinojosa, Román, & Meléndez, 2018; Meléndez & Hinojosa, 2017). The slow response from the federal government and the Federal Emergency Management Administration paired with inappropriate funding slowed restoration and recovery efforts; because of this staying or leaving became a choice between life and death (Willison, Singer, Creary, & Greer, 2019). The hurricane had a significant effect in the life of those affected by it, and some still have not fully recovered from its impact.

Similar to previous natural disasters, hurricane Maria complicated the process of estimating and projecting the population of Puerto Rico. This challenges have been summarized in previous work, of which the case study of hurricane Andrew remains a seminal text on demography of disaster (Smith, 1996). For Puerto Rico, the Federal Oversight and Management Board (FOMB) was presented with results that included three displacement scenarios: (1) a “baseline forecast” equivalent to the displacement of 220,000 persons, (2) a weak Maria effect with 50,000 persons displaced, and (3) a strong Maria effect with 500,000 persons displaced by Hurricane Maria (Stone, 2017). Furthermore, during this presentation the FOMB was presented with a series of alternative scenarios that do not fit the demographic reality of Puerto Rico or

ignore its past. Contrary to this, the Puerto Rico Institute of Statistics (PRIS) limited their presentation to highlighting the difficulties of estimating the population, and the numerous revisions and limitations faced by those modeling the population of Puerto Rico before hurricane Maria (Marazzi-Santiago, 2017). The public stance of PRIS regarding the displacement of the population was “*it is still too early to tell*”.

Population estimates play a crucial role in decision-making at both the public and private sector. In the case of Puerto Rico, pre- and post-hurricane Maria they are essential to determine the future of the island and the sustainability of the financial recovery as forecasted by the fiscal plan (Government of Puerto Rico, 2018). Similar to the case of hurricane Andrew, discussed by Smith (1996) the accuracy and timeliness of these estimates is critical to the success of Puerto Rico. I am not aware of any study that describes the use of the demographic balancing equation and administrative data to produce reliable population estimates for Puerto Rico and will highlight its pertinence following natural disasters and in light of the historical accidents in the production of population estimates.

The objective of the present study is to propose a reliable and timely method for the production of population estimates for Puerto Rico on a month-to-month basis, relying in publicly available administrative data. First, I describe the past problems with population estimates in Puerto Rico. Second, I discuss the pertinence and applicability of the demographic balancing equation to produce population estimates for Puerto Rico and present estimates for the 2000-2018 period using this method. Third, I compare the month-to-month estimates with the estimates produced by the U.S. Census Bureau. I close with a discussion of the challenges of producing population estimates, projections, and forecasts following natural disasters.

Population estimates and demographic products in Puerto Rico before Hurricane Maria

The production of population estimates for Puerto Rico has been a challenge since mid-2000s. For example, the publication of the 2010 decennial count of 3,725,789 people for Puerto Rico surprised many who were expecting the population to be close to 4 million by 2010 (Figueroa-Rodríguez, Rivera-Negrón, & Rodríguez-Figueroa, 2012; U.S. Census Bureau, 2010). In 2000, the population count was 3,808,610 people, this means that during the decade the population declined by 2.17% (U.S. Census Bureau, 2000). None of the government agencies or programs tasked with demographic issues had projected a population decline. On the contrary, estimates for the pre-2010 era placed the population close to 4 million.

In Table 1, I present the population estimates produced by the Puerto Rico Planning Board (PRPB), the U.S. Census Bureau (original and revised), and the decennial counts for the 2000-2010 period. Both the U.S. Census and the PRPB estimated that the decade would be one of population increase with the more than 3.9 million persons in the middle of the decade and in the case of the PRPR more than 4 million persons by 2009. Thus, the population decline evidenced with the publication of the decennial counts woke the island and stakeholders to a “new reality”. The revised estimates for Puerto Rico, published by the U.S. Census Bureau placed the population of Puerto Rico at its highest point in 2004 (3.8 million) with the first population decline happening in 2005.

Table 1. Decennial counts and estimates for the population of Puerto Rico, 2000-2010				
	U.S. Census (Original Estimates)	Puerto Rico Planning Board	U.S. Census (Revised Estimates)	Decennial Census
2000	3,814,413	3,808,610	3,810,605	3,808,610
2001	3,837,768	3,832,350	3,818,774	--
2002	3,858,272	3,856,352	3,823,701	--
2003	3,876,637	3,880,607	3,826,095	--
2004	3,893,931	3,905,118	3,826,878	--
2005	3,910,722	3,929,885	3,821,362	--
2006	3,926,744	3,948,044	3,805,214	--
2007	3,941,235	3,966,375	3,782,995	--
2008	3,954,553	3,984,888	3,760,866	--
2009	3,967,288	4,003,578	3,740,410	--
2010	--	4,022,446	3,722,133	3,725,789
Source: U.S. Census Bureau, Puerto Rico Planning Board				
Note: Decennial counts are for April 1 and estimates are for July 1.				

Despite what was experienced on that decade, the production of estimates and projections by local agencies for Puerto Rico did not improve. For example, the PRPB published three supplements to the Puerto Rico Economic Summary on each of the demographic processes (Puerto Rico Planning Board, 2013a, 2013b, 2014). An in-depth discussion of each supplement is beyond the scope of this article, but I will highlight elements from each report to support my assessment. First, in the Natality Supplement forecasted the number of births in Puerto Rico to be zero by 2043 (Puerto Rico Planning Board, 2013b). The Mortality Supplement forecasted the number of deaths with a model that did not account month-to-month variation in the number of deaths which produced a “flat” forecast for the future until 2050 (Puerto Rico Planning Board, 2013a). Finally, the Migration Supplement used arithmetic extrapolation techniques to forecast the net migration despite evident “ebbs and flows” in the net migration in previous years (Puerto Rico Planning Board, 2014).

Also in 2014, PRIS approved resolution 2014-03 where they ordered the PRPB to stop distributing county-level estimates for Puerto Rico that included estimates for 2011 through 2025

(these would be projections or forecasts, not estimates). In May 2015, the PRPB produced projections for Puerto Rico up until 2027, the revised version published in May 2017 presented estimates that were not consistent with the demographic reality of Puerto Rico. A clear example is a positive balance until 2019 when vital records indicate this is not true since 2016 where the natural balance was -1,271 (Puerto Rico Planning Board, 2017). This reaffirms that the production of population estimates and other demographic products has been difficult for Puerto Rico during the last 15 years. Hurricane Maria would present additional challenges to the already difficult task of determining the current and future population of Puerto Rico.

Population estimates following Hurricane Maria

The displacement of the population of Puerto Rico following Hurricane Maria brought with it discussions about the size of the population and the sustainability of the fiscal plan which relied upon a stable tax-base to allow for the repayment of the debt to bondholders (Puerto Rico Fiscal Agency and Financial Advisory Authority, 2017). If outmigration accelerate, it is likely that the government of Puerto Rico will face challenges in meeting the milestones included in the fiscal plan. Between September 20 and November 7, approximately 100,000 people left Puerto Rico, alone this number exceeded the number of persons who left Puerto Rico in 2015 (Santos-Lozada, 2017). A study by the Center for Puerto Rican Studies at CUNY suggested that the island would lose up to 470,335 residents or 14% of its population by 2020 (Meléndez & Hinojosa, 2017) if the acceleration of migration continued. However, it remained difficult to determine whether those who had left had done it permanently, temporarily and whether their return depended on the pace of recovery.

Smith (1996) outlines the multiple instances where population estimates play a crucial role regarding disaster recovery; In Puerto Rico, the situation was not different. FEMA needed estimates to determine the allocation of resources; other federal government agencies needed estimates to conduct impact assessments, and the FOMB and Government of Puerto Rico needed estimates to modify the fiscal plan and its economic forecasts in light of the demographic changes that were occurring in the aftermath of Hurricane Maria. Nevertheless, a growing body of literature has addressed the difficulties of producing post-disaster estimates, provide guidance on this endeavor and have highlighted the reliability of administrative data to aid in this effort (Plyer, Bonaguro, & Hodges, 2010; Smith & McCarty, 1996). Despite this, no effort has used administrative records to produce population estimates following hurricane Maria in Puerto Rico.

Perhaps the most important effort geared toward addressing the demographic changes in Puerto Rico after Hurricane Maria came in the form of a *Listening Session* hosted by the FOMB on November 16 2017. This session included presentations regarding the population of Puerto Rico by four participants: (1) PRPB, (2) Lyman Stone a consultant for FOMB, (3) the Puerto Rico Institute of Statistics and (4) the Center for Puerto Rican Studies (Marazzi-Santiago, 2017; Meléndez & Hinojosa, 2017; Poueymirou, 2017; Stone, 2017). A consensus derived from these presentations is the challenging nature of producing post-disaster estimates. Among all of them, two presentations highlighted trends and patterns of demographic processes in Puerto Rico, highlighting the challenges in accessing the data required to study the demography of Puerto Rico. While PRIS and PRPB did not venture into forecasting the population, the consultant for the FOMB did (Stone, 2017). While some emphasized on the challenges of accessing data and other forecasted the population, nobody addressed the subjacent issue of the current population of the island.

A new model of population estimates that relies on administrative records

Demographic Balancing Equation

How many persons live in Puerto Rico? This has been the question for many years. Given that, Puerto Rico is an island and no migration (or a small amount) occurs away from a ports of exit the demographic balancing equation can be used to produce estimates of the population on a monthly basis for Puerto Rico. The demographic balancing equation is the most basic method of demography (Shryock, Seigel, & Stockwell, 1976). It is the best way to decompose population change into two main components: (1) natural growth and (2) net migration. Natural growth is the difference between the number of births (B) and the number of deaths (D). Positive natural growth indicates more births than deaths for the period of interest, while negative natural growth is the result more deaths than births. Net migration is the difference between those arriving (I) and leaving (O) through a port of entry. Positive net migration represents more arrivals than departures, while negative net migration represents more departures than arrivals.

Because Puerto Rico has a good vital statistics system (births and deaths),and records every person who leaves or arrive through either locally by the Puerto Rico Port Authority or by federal (Rodriguez-Ayuso & Marazzi-Santiago, 2010; U.S. Bureau of Transportation Statistics, 2018) the demographic balancing equation (Formula 1) can be used to produce monthly estimates.

$$P_t = P_0 + B - D + I - O \quad (\text{Formula 1})$$

For the estimation process discussed in this article, let P_t be the population at the time of interest, P_0 a base population (decennial counts), B the births between P_t and P_0 , D the deaths between P_t and P_0 , I the arrivals between P_t and P_0 , and O the departures between P_t and P_0 . If the systems capture the totality of the persons involved in these processes, then the population estimates

produced with the formula are the most accurate way of estimating the population of Puerto Rico or any other island territory. Given the need for population estimates and how important they are following Hurricane Maria, I will produce and evaluate population estimates for the 2000-2018 period illustrating each step of the process.

Data

Census Counts

Perhaps, the easiest element of this process the decennial population counts for Puerto Rico for 2000 and 2018. I accessed these numbers through the U.S. Census Bureau (Table 1). In 2000, the population of Puerto Rico was 3,808,610 persons, while the population for 2010 was 3,725,789 persons (U.S. Census Bureau, 2000, 2010). I will use the count for 2000 as the base population (P_0). The estimate derived from the balancing equation for March 2010 will be compared to the 2010 decennial count to evaluate the accuracy of the model.

Puerto Rico Vital Statistics System: Births and Deaths

I use data from the Puerto Rico Vital Statistics System (PRVSS) births and death records to account for natural growth within the demographic balancing equation model. The Puerto Rico Vital Statistics System captures virtually every birth and death that occurs in Puerto Rico (Rodriguez-Ayuso & Marazzi-Santiago, 2010). I use counts of events by year and month for the 2000-2018 period to produce month-to-month estimates for the population of Puerto Rico. The lag in the publication of totals and updates in these figures due to delayed data entry could constitute a source of error within this component of population growth (or decline) in Puerto Rico. The monthly time series for births and deaths for 2000-2018 are included in Supplementary Tables 1 and 2, and natural growth estimates are included in Supplementary Table 3.

Passenger flows

The U.S. Bureau of Transportation Statistics publishes monthly counts for passenger traffic on domestic and international flights on a periodical basis (U.S. Bureau of Transportation Statistics, 2018). According to the current regulations, the data covers all U.S. certificated air carriers. The publication of this data is delayed by approximately six months. Currently, the data is available up until September 2018. Because of this, the estimates will be produced until September 2018. Data used to measure net migration are included in Supplementary Tables 4-6.

A summary of results

Natural Growth

The first element of the demographic balancing equation is the difference between births and deaths, also known as natural growth. Using the data discussed previously, I estimate the natural growth for Puerto Rico between 2000 and 2018. Monthly estimates for natural growth are presented in Supplementary Table 3 and yearly estimates are presented in Table 2. In 2000, the natural growth for Puerto Rico was over 20,000 more births than deaths. This figure had more than halved by 2011. The first year with a negative natural growth was 2016 where there were 1,271 more deaths than births. This is to say, the population decline for Puerto Rico was mostly driven by net migration until 2016, where both components of population change were negative.

Table 2: Population estimates using the demographic balancing equation for Puerto Rico, 2000-2018				
Year	Components of Growth			Estimate^b
	Base Population	Natural Growth	Net Migration	
2000 ^a	3,808,610	24,250	-37,929	3,794,931
2001	3,794,931	26,545	-8,295	3,813,181
2002	3,813,181	24,456	-29,682	3,807,955
2003	3,807,955	21,961	-24,809	3,805,107
2004	3,805,107	21,639	-21,686	3,805,060
2005	3,805,060	20,710	-48,060	3,777,710
2006	3,777,710	20,108	-61,549	3,736,269
2007	3,736,269	17,406	-47,829	3,705,846
2008	3,705,846	16,583	-44,706	3,677,723
2009	3,677,723	15,708	-20,129	3,673,302
2010	3,673,302	12,891	-45,833	3,640,360
2011	3,640,360	11,131	-38,226	3,613,265
2012	3,613,265	9,101	-46,588	3,575,778
2013	3,575,778	7,214	-49,233	3,533,759
2014	3,533,759	4,569	-83,257	3,455,071
2015	3,455,071	2,838	-92,979	3,364,930
2016	3,364,930	-1,271	-84,264	3,279,395
2017	3,279,395	-6,684	-293,992	2,978,719
2018 ^c	2,978,719	-6,214	50,615	3,023,120
Note: a. The base population for 2000 and other calculations begin in April 1.				
b. The base population for 2001-2018 is the end of the year estimate for the previous year.				
c. The population estimate for 2018 is until September 1, 2018.				

Net Migration or Net Passenger Traffic

The second element of the demographic balancing equation is the difference between incoming passengers and outbound passengers. Since the beginning of the period of analysis, the net migration was negative. Monthly estimates for net migration are presented in Supplementary Table 6 and yearly estimates are presented in Table 2. Between 2004 and 2016, the net migration has fluctuated between -20,129 and -92,979 persons who left Puerto Rico. In 2017, the year of hurricane Maria's landfall, the yearly net migration was -293,992 which more than doubles the highest net migration figure to the preceding period. The limited data available for 2018,

indicates that some persons have returned to Puerto Rico as we find the only positive net migration figure for the period of analysis.

Monthly population estimates

Monthly-to-month population estimates and monthly population change figures are presented in Supplementary Tables 7 and 8, respectively. Yearly estimates are presented in Table 2. Estimates produced using the demographic balancing equation for Puerto Rico indicates that the onset of population decline was 2002; two years earlier than the U.S. Census Estimates indicate (see Table 1). Monthly population estimates and population change figures presented in Supplementary Tables 7 and 8 indicate that within years, and even at the beginning of the period of analysis (May 2000) the population of Puerto Rico was experiencing ebbs and flows. In this period of analysis, 123 or 53.95% of the months were of negative population change for the total population.

Furthermore, only in three months of 2000, population decline is observed; this was the year with the lowest number of months with decline. Following 2001, up until 2008, up to half of the months of the year were of population decline. After 2008, this pattern switched with the majority of the months being of population decline for Puerto Rico with 2013 and 2014 having eight out of twelve or 66.67% of the months with population decline. The year preceding hurricane Maria the island experienced population decline on 9 months which is equivalent to 75% of the months of the year. In 2017, the island experienced population decline in 10 months or 83.33% of the months of the year. Noteworthy about this figure is that December 2017 had a negative net migration; this is something unobserved in the mathematical derivations included in Supplementary Table 8.

I estimate that the population of Puerto Rico was 3.28 million by December 2016. The population fluctuated between 3.2 million and 3.1 million before hurricane Maria. Following the hurricane, the population fell below 3 million in December 2017. This was short-lived; in January 2018, the population went back to over 3 million and remained at this level up until September 2018, where I estimate the population to be 3,023,120 persons.

Table 3: Population estimates using the demographic balancing equation and produced by U.S. Census Bureau for Puerto Rico, 2000-2018				
Year	Month-to-month^a	U.S. Census^b	Difference	% Difference
2000	3,771,011	3,810,605	-39,594	-1.04
2001	3,768,668	3,818,774	-50,106	-1.31
2002	3,785,158	3,823,701	-38,543	-1.01
2003	3,771,395	3,826,095	-54,700	-1.43
2004	3,771,651	3,826,878	-55,227	-1.44
2005	3,761,519	3,821,362	-59,843	-1.57
2006	3,736,100	3,805,214	-69,114	-1.82
2007	3,694,860	3,782,995	-88,135	-2.33
2008	3,657,483	3,760,866	-103,383	-2.75
2009	3,654,944	3,740,410	-85,466	-2.28
2010	3,626,900	3,721,525	-94,625	-2.54
2011	3,603,102	3,678,732	-75,630	-2.06
2012	3,567,194	3,634,488	-67,294	-1.85
2013	3,532,779	3,593,077	-60,298	-1.68
2014	3,465,137	3,534,874	-69,737	-1.97
2015	3,376,081	3,473,166	-97,085	-2.80
2016	3,282,751	3,406,495	-123,744	-3.63
2017	3,215,774	3,325,001	-109,227	-3.29
2018	3,040,578	3,195,153	-154,575	-4.84
Note: a. Estimates included are for end of month June or July 1				
b. Estimates produced by the U.S. Census Bureau are for July 1				

Evaluation of the estimates

I initiated the month-to-month estimates using the decennial count for 2000 as a base population. This allows me to use the decennial count for 2010 to measure the accuracy of the model. The

population estimate for April 1, 2010 was 3,669,676 people and the decennial count was 3,722,789 people. This represents a difference of 1.51% with the month-to-month estimate, produced with the balancing equation, estimating a lower population than the decennial count.

In Table 3, I compare the latest vintage of population estimates for Puerto Rico with estimates for April 1 of each year of this decade. Similar to the observed differences for the decennial count and the month-to-month model, for July 1 within the period of 2000-2006 the difference between the month-to-month model and the estimates produced by the U.S. Census Bureau remained below 2%. Between 2007 and 2015, the percent difference remained over 2% for 6 years. In 2016, the year before hurricane Maria the percent difference was 3.63%, while the percent difference for 2017 was -3.29%. Furthermore, in 2018 the percent difference between the month-to-month model and the U.S. Census Bureau estimates was 4.84%. As time passes and after hurricane Maria the estimates produced by the U.S. Census Bureau are increasingly different from the ones produced using the demographic equation (month-to-month models). Despite initial concordance between the models, one of them is not modeling the population of Puerto Rico accurately for the most recent years.

Discussion

Similar to the lessons learned in making post-Hurricane Andrew population estimates as discussed in the work of Smith (1996), a number of lessons learned in making post-Hurricane Maria population estimates are worthy of attention. The most important, is that following natural disasters there is an immediate need for data, which is exacerbated by the delay in updates and release of official data sources. Oftentimes, in the aftermath of the hurricane, surveys and indirect methods of estimation are powerful sources of information; however, these should not be the sole source of information. For example, the work of by Melendez and Hinojosa, Terralytics

and Santos-Lozada provided insights as to displacement of the population (Echenique & Melgar, 2018; Meléndez & Hinojosa, 2017; Santos-Lozada, 2017) but these indirect estimation methods provided a snapshot of displacement while monitoring passenger flow could have provided an updated/continuous glimpse at the patterns and trends of this demographic process.

Smith (1996) contemplated that survey data is needed before any detailed demographic analysis can be performed. The availability of the internet has provided opportunities to collect information that were not available when the “demography of disaster” emerged (1996). In spite of this, the challenges and pitfalls of post-disaster data collection persist; indeed a wide body of literature is cautious of online surveys and of the data collected with them spelling the perils of non-representative data with the phrase “*No data are better than bad data*” (Duda & Nobile, 2010). Despite their limitations and lack of generalizability, these instruments provide a quick assessment of what is happening in the affected area. After this initial assessment is done, one would expect researchers and government officers to turn to administrative data sources because they be used to form the basis of sound, relevant, and timely county-level population estimates following catastrophic events in the United States (Plyer et al., 2010). Because migration is the most difficult component to estimate, this model relies on the passenger flight record, an administrative data source, to approximate migration dynamics on a month-to-month basis which constitutes a direct count of movement and not an estimate or approximation (Rowland, 2003).

The public, academic and private sector also arise controversies that have affected other areas stricken by natural disasters. For example, in the estimation of the mortality attributable for Hurricane Maria, some level of consistency was found across different estimation techniques but widely covered figures allowed government officers to state that the estimates were “all over the

place” (Sandberg et al., 2019). A second example comes from migration, although researchers were cautious to call the temporary displacement of persons migration, these displacement figures were used to forecast the population of Puerto Rico and these results were given to bodies that make policy decisions (Government of Puerto Rico, 2018; Stone, 2017). The private sector and bondholders monitored estimates with an eagle eye; this because the stability of the population and the repayment capability could significantly affect their investment portfolios and financial positions. As such, the production of post-disaster estimates can have implications to the population we are interested in studying.

The model discussed in this article also constitutes an answer to the call by Smith (1996) asking for “*focus on several points in time*”. As described and outlined, we can produce monthly estimates for Puerto Rico to closely monitor the total population following a natural disaster. Although informative, the production of demographic products based on unrealistic assumptions (such as those derived following “shocks”) could misled decisions by the public and private sectors. For example, estimating migration and not contemplating the temporary nature of some moves could bias estimates and the decisions made upon this data. For example, hurricane Maria displaced persons but some have returned to Puerto Rico, and some have decided to stay abroad. The present study provides a way of monitoring the total population of Puerto Rico on a month-to-month basis which and it can better inform decisions by both the public and private sectors.

Strengths and Limitations

The strengths of this paper is that it uses a simple mathematical model to produce estimates for Puerto Rico, a model that is applicable to other island territories. This paper relies on publicly available information, but government organizations could engage in inter-agency collaborations

to access this data in a timely manner. It may be possible that a small amount of persons arrives to Puerto Rico via airplane and leave via boats. A future version of this model that incorporates marine traffic could produce estimates that address this source of bias. Currently, boat traffic and maritime passenger counts are not publicly available.

Conclusion

The Government of Puerto Rico, the FOMB, and federal stakeholders can leverage the demographic balancing equation and preliminary administrative records to produce month-to-month estimates for Puerto Rico to inform decision-making processes. The occurrence of Hurricane María provides an opportunity to create a model that can adapt to the circumstances, such as changes in demographic dynamics, and provide timely population estimates. This article describes a simple approach to producing population estimates for Puerto Rico and other island territories. It describes a basic formulation of the components of population change, through the demographic balancing equation, and the administrative records required to produce month-to-month estimates with error metrics that fall within the acceptable levels.

Perhaps more important, it fills addresses the persistent issues of inaccurate population estimates for Puerto Rico. It also produces estimates, which can be used to inform the decisions during this period of economic crisis. The growing interest in Puerto Rico by the financial and political sectors underscore the importance of this work to inform decisions that can affect economic forecasts and fiscal plans that serve as blueprints for the economic recovery of the island.

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Supplementary Table 1: Births in Puerto Rico, 2000-2018

Year	Month of Birth											
	January	February	March	April	May	June	July	August	September	October	November	December
2000	5,011	4,454	4,818	4,276	4,597	4,529	4,684	5,265	5,584	5,515	5,433	5,294
2001	4,839	4,284	4,637	4,229	4,529	4,234	4,529	5,057	4,941	5,111	4,779	4,814
2002	4,641	3,983	4,055	4,181	4,178	3,993	4,237	4,763	4,721	4,876	4,583	4,660
2003	4,489	3,886	3,911	4,011	4,011	3,755	4,175	4,374	4,703	4,602	4,224	4,662
2004	4,161	3,805	4,198	3,900	3,866	3,939	4,037	4,609	4,813	4,605	4,554	4,752
2005	4,159	3,723	4,081	3,793	3,894	4,007	4,022	4,734	4,757	4,473	4,563	4,482
2006	3,868	3,624	3,887	3,438	3,975	3,794	3,786	4,652	4,590	4,500	4,305	4,326
2007	4,087	3,511	3,712	3,472	3,741	3,495	3,637	4,385	4,284	4,314	4,110	3,979
2008	3,923	3,470	3,458	3,463	3,597	3,495	3,778	4,217	4,182	4,115	3,698	4,287
2009	3,720	3,332	3,583	3,488	3,404	3,424	3,617	3,894	4,308	4,006	3,752	4,305
2010	3,567	3,239	3,617	3,084	3,241	3,310	3,325	3,738	3,933	3,721	3,608	3,864
2011	3,287	2,987	3,394	3,030	3,105	3,355	3,236	3,773	3,993	3,624	3,627	3,722
2012	3,416	3,056	3,001	2,837	3,142	2,946	3,205	3,512	3,457	3,683	3,365	3,354
2013	3,132	2,773	2,795	2,881	3,033	2,768	3,049	3,088	3,381	3,401	3,061	3,218
2014	3,204	2,686	2,770	2,686	2,717	2,530	2,885	2,921	3,105	3,058	2,793	3,140
2015	2,829	2,415	2,662	2,449	2,484	2,306	2,430	2,455	3,001	2,775	2,642	2,793
2016	2,453	2,299	2,380	2,232	2,378	2,349	2,189	2,476	2,600	2,289	2,345	2,352
2017	2,153	1,864	2,054	1,939	2,048	1,992	1,941	2,095	2,069	2,174	2,146	1,842
2018	1,774	1,571	1,581	1,604	1,628	1,670	1,760	1,983	1,978	--	--	--

Note: Births for 2018 were accessed through www.cdc.gov/nchs/ness/vsrr/provisional-tables.htm on March 20, 2019

Supplementary Table 3: Natural Balance in Puerto Rico, 2000-2018

Monthly Natural Balance												
Year	January	February	March	April	May	June	July	August	September	October	November	December
2000	2,223	1,956	2,185	1,845	2,183	2,254	2,396	2,956	3,382	3,151	3,117	2,966
2001	2,367	1,972	2,139	1,894	2,125	1,891	2,090	2,708	2,436	2,418	2,266	2,239
2002	2,122	1,700	1,545	1,916	1,800	1,738	1,883	2,364	2,392	2,565	2,187	2,244
2003	1,948	1,661	1,496	1,754	1,581	1,387	1,794	2,036	2,289	2,227	1,874	1,914
2004	1,460	1,280	1,683	1,488	1,437	1,474	1,688	2,284	2,556	2,235	2,129	1,925
2005	1,206	1,151	1,487	1,392	1,416	1,547	1,648	2,313	2,341	2,080	2,184	1,945
2006	1,474	1,359	1,349	960	1,615	1,552	1,466	2,221	2,252	2,091	1,876	1,893
2007	1,535	1,283	1,199	936	1,149	1,109	1,254	2,046	1,994	1,875	1,682	1,344
2008	1,302	863	954	1,154	1,153	1,211	1,437	1,862	1,904	1,722	1,262	1,759
2009	1,240	950	1,006	1,098	858	932	1,085	1,616	2,086	1,556	1,407	1,874
2010	1,175	1,012	1,122	786	792	905	847	1,163	1,652	1,253	1,096	1,088
2011	559	624	624	582	628	897	768	1,330	1,634	1,141	1,267	1,077
2012	797	608	426	359	763	391	759	1,042	1,003	1,263	910	780
2013	554	397	90	567	634	431	564	591	912	1,003	793	678
2014	720	470	281	290	238	143	465	385	610	572	144	251
2015	85	12	235	190	145	160	50	183	743	384	374	277
2016	-288	-293	-80	-8	68	-5	-264	49	237	-63	-132	-492
2017	-741	-451	-440	-453	-342	-377	-426	-226	-859	-866	-525	-978
2018	-1,065	-888	-1,076	-639	-757	-575	-601	-358	-255	--	--	--

Note: Calculates as the difference between births and deaths (B-D)

Supplementary Table 4: Incoming Passengers in Puerto Rico, 2000-2018

Year	Month of Arrival											
	January	February	March	April	May	June	July	August	September	October	November	December
2000	453,309	414,501	463,244	469,170	410,739	470,115	540,441	452,480	290,524	339,406	432,465	469,568
2001	471,738	420,704	476,815	462,193	383,994	474,829	507,496	431,780	212,496	249,868	339,930	413,853
2002	422,807	373,113	461,245	391,107	361,282	438,137	496,497	409,896	253,130	296,741	361,783	476,582
2003	444,147	376,459	427,062	393,735	375,503	441,752	535,897	450,236	265,364	314,217	378,090	490,574
2004	487,083	435,229	470,132	493,688	424,513	520,310	611,793	478,582	283,231	351,441	405,159	480,731
2005	487,078	417,557	529,552	457,740	439,034	531,578	638,863	479,797	293,622	344,173	425,210	503,006
2006	508,543	429,640	493,949	506,749	446,053	526,354	609,016	471,210	297,742	342,994	423,676	488,997
2007	480,277	414,217	496,301	473,005	435,245	524,795	589,583	490,734	324,016	371,874	446,650	486,010
2008	474,947	424,826	520,182	437,200	427,964	499,522	557,449	461,017	244,694	276,173	324,052	406,002
2009	387,219	335,369	377,763	365,580	359,494	422,622	472,863	395,747	267,705	300,711	354,142	427,343
2010	426,015	358,376	427,836	394,615	371,396	443,989	503,326	404,511	276,350	308,129	346,534	413,200
2011	405,899	352,022	413,784	368,722	341,456	416,531	485,620	367,319	250,350	290,634	337,909	407,986
2012	388,939	351,360	409,113	396,478	366,559	453,242	501,163	405,650	278,029	301,976	349,436	416,999
2013	398,255	348,666	431,018	355,508	347,024	422,325	478,195	392,090	258,886	294,041	334,207	431,418
2014	394,056	342,111	428,608	378,584	363,444	443,473	498,241	399,213	262,798	303,622	337,665	435,682
2015	406,705	352,110	412,387	363,903	360,805	430,327	494,366	400,900	282,132	322,147	372,251	465,747
2016	445,664	383,498	454,055	383,768	378,557	450,860	518,006	407,327	281,614	307,471	366,387	465,646
2017	438,506	365,794	446,823	422,764	383,870	476,698	546,560	431,019	149,848	159,465	215,356	332,710
2018	359,921	295,420	382,110	371,548	380,322	467,176	508,774	412,995	277,535	--	--	--

Note: Data for passenger flow was available until September 2018 at the time of submission.

Supplementary Table 6: Net Passenger flow in Puerto Rico, 2000–2018

Year	Monthly Net Passenger Flow											
	January	February	March	April	May	June	July	August	September	October	November	December
2000	-2,730	5,165	-11,873	-5,020	-34,075	-4,786	9,646	320	-16,260	4,419	4,679	3,148
2001	133	5,360	-8,436	-14,944	-30,201	9,437	18,852	-5,048	-16,548	3,665	6,796	22,639
2002	-12,775	7,769	-8,069	-3,822	-22,652	705	10,192	-10,706	-12,250	141	-1,656	23,441
2003	643	1,923	-9,062	-10,368	-26,868	-2,655	16,195	-5,887	-14,521	1,368	-1,822	26,245
2004	-42	1,082	-10,039	-8,574	-31,206	6,501	17,581	-3,177	-19,507	5,207	-835	21,323
2005	-6,533	13,324	-8,564	-11,514	-36,618	-1,835	19,263	-143	-24,308	-353	948	8,273
2006	7,252	6,216	-7,340	-16,202	-43,936	4,091	6,002	-7,059	-18,161	-4,089	1,807	9,870
2007	2,884	4,582	-6,021	-18,407	-32,966	1,308	7,481	-6,519	-16,792	-1,292	4,217	13,696
2008	2,129	5,491	-9,112	-19,727	-32,562	-1,219	11,988	-7,824	-18,697	2,825	-3,731	25,733
2009	1,124	9,429	-15,116	-13,645	-19,828	9,173	12,114	-9,017	-15,750	-673	-5,906	27,966
2010	-2,022	6,629	-11,542	-13,478	-37,393	5,612	20,650	-14,716	-16,534	904	-2,444	18,501
2011	3,978	7,858	-9,602	-17,287	-34,473	8,354	9,772	-6,866	-16,790	-2,129	2,905	16,054
2012	779	5,502	-14,176	-12,843	-29,447	770	7,193	-6,268	-15,489	1,738	-1,286	16,939
2013	2,902	5,961	-5,552	-20,185	-25,782	-3,016	7,436	-15,616	-16,207	-3,124	-2,710	26,660
2014	-2,416	4,256	-10,373	-25,549	-30,605	-6,077	5,137	-20,293	-17,225	1,222	-5,331	23,997
2015	1,737	771	-14,757	-24,126	-31,872	-11,570	981	-20,907	-16,855	381	-3,978	27,216
2016	-2,113	-4,231	-4,899	-24,556	-42,235	-3,539	1,748	-11,259	-15,146	-6,905	2,239	26,632
2017	-7,264	6,657	-4,458	-23,734	-29,955	-2,063	1,839	-18,689	-44,723	-99,197	-50,250	-22,155
2018	70,690	12,431	1,031	-3,895	-11,577	-1,821	-233	140	-16,151	--	--	--

Note: Data for passenger flow was available until September 2018 at the time of submission.

Supplementary Table 7: Monthly Population Estimates for Puerto Rico, 2000-2018

Year	Monthly Population for Puerto Rico											
	January	February	March	April	May	June	July	August	September	October	November	December
2000	--	--	--	3,805,435	3,773,543	3,771,011	3,783,053	3,786,329	3,773,451	3,781,021	3,788,817	3,794,931
2001	3,797,431	3,804,763	3,798,466	3,785,416	3,757,340	3,768,668	3,789,610	3,787,270	3,773,158	3,779,241	3,788,303	3,813,181
2002	3,802,528	3,811,997	3,805,473	3,803,567	3,782,715	3,785,158	3,797,233	3,788,891	3,779,033	3,781,739	3,782,270	3,807,955
2003	3,810,546	3,814,130	3,806,564	3,797,950	3,772,663	3,771,395	3,789,384	3,785,533	3,773,301	3,776,896	3,776,948	3,805,107
2004	3,806,525	3,808,887	3,800,531	3,793,445	3,763,676	3,771,651	3,790,920	3,790,027	3,773,076	3,780,518	3,781,812	3,805,060
2005	3,799,733	3,814,208	3,807,131	3,797,009	3,761,807	3,761,519	3,782,430	3,784,600	3,762,633	3,764,360	3,767,492	3,777,710
2006	3,786,436	3,794,011	3,788,020	3,772,778	3,730,457	3,736,100	3,743,568	3,738,730	3,722,821	3,720,823	3,724,506	3,736,269
2007	3,740,688	3,746,553	3,741,731	3,724,260	3,692,443	3,694,860	3,703,595	3,699,122	3,684,324	3,684,907	3,690,806	3,705,846
2008	3,709,277	3,715,631	3,707,473	3,688,900	3,657,491	3,657,483	3,670,908	3,664,946	3,648,153	3,652,700	3,650,231	3,677,723
2009	3,680,087	3,690,466	3,676,356	3,663,809	3,644,839	3,654,944	3,668,143	3,660,742	3,647,078	3,647,961	3,643,462	3,673,302
2010	3,672,455	3,680,096	3,669,676	3,656,984	3,620,383	3,626,900	3,613,642	3,608,106	3,592,950	3,622,119	3,620,771	3,640,360
2011	3,644,897	3,653,379	3,644,401	3,627,696	3,593,851	3,603,102	3,613,642	3,608,106	3,592,950	3,591,962	3,596,134	3,613,265
2012	3,614,841	3,620,951	3,607,201	3,594,717	3,566,033	3,567,194	3,575,146	3,569,920	3,555,434	3,558,435	3,558,059	3,575,778
2013	3,579,234	3,585,592	3,580,130	3,560,512	3,535,364	3,532,779	3,540,779	3,525,754	3,510,459	3,508,338	3,506,421	3,533,759
2014	3,532,063	3,536,789	3,526,697	3,501,438	3,471,071	3,465,137	3,470,739	3,450,831	3,434,216	3,436,010	3,430,823	3,455,071
2015	3,456,893	3,457,676	3,443,154	3,419,218	3,387,491	3,376,081	3,377,112	3,356,388	3,340,276	3,341,041	3,337,437	3,364,930
2016	3,362,529	3,358,005	3,353,026	3,328,462	3,286,295	3,282,751	3,284,235	3,273,025	3,258,116	3,251,148	3,253,255	3,279,395
2017	3,271,390	3,277,596	3,272,698	3,248,511	3,218,214	3,215,774	3,217,187	3,198,272	3,152,690	3,052,627	3,001,852	2,978,719
2018	3,048,344	3,059,887	3,059,842	3,055,308	3,042,974	3,040,578	3,039,744	3,039,526	3,023,120	--	--	--

Note: Calculated using the demographic balancing equation, some differences may emerge based updated data in the administrative records

Note 2: Data for passenger flow was available until September 2018 at the time of submission.

