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Data integration for measuring migration

The impact of hurricane Maria: the US Census Bureau's experience combining survey-based estimates and "Big Data" to produce 2018 Puerto Rico net migration estimates

Note by United States Census Bureau*

Summary

On September 20, 2017, Hurricane Maria made landfall on the island of Puerto Rico resulting in mass devastation. This not only impacted residents of the island, resulting in large migration flows from Puerto Rico to the United States, but also the quality of data typically used to measure migration patterns, forcing the Census Bureau to modify its existing method to produce its Vintage 2018 Puerto Rico estimates. The previous methodology utilized the American Community Survey (ACS), and its counterpart, the Puerto Rico Community Survey (PRCS), to estimate migration to and from Puerto Rico and the United States. In the aftermath of the hurricane, these data sources did not adequately measure net migration between Puerto Rico and the United States, necessitating a new approach.

This paper describes the methodology the US Census Bureau used to integrate ACS/PRCS data with "Big Data," specifically monthly Airline Passenger Traffic data from the Bureau of Transportation Statistics. While the ACS did not adequately measure outmigration from Puerto Rico to the United after Hurricane Maria, monthly airline data did show a mass exodus of persons from the Island to the United States during this time period. Historically, APT data has consistently shown higher net out migration from Puerto Rico to the United States than ACS/PRCS estimates. To account for this inherent difference between data sources, the revised method "blends" ACS/PRCS and APT data. This was accomplished by calculating the ratio

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of ACS to APT net migration for Puerto Rico and applying it to net Puerto Rico-US migration measured from 2017 APT data. The result of this method change is a July 1, 2018, estimate of the Puerto Rico population that takes into account the impact of Hurricane Maria. Further, we used an Autoregressive integrating moving average (ARMA) model to evaluate the "blended" approach, which yielded similar results.

I. Introduction

1. Natural disasters can impact the distribution of population, namely through the movement of persons away from affected areas, as well as possible deaths resulting from cataclysmic events. As natural disasters increase in frequency and magnitude1, so do the needs for population estimates programs to accurately measure their impact, often requiring different data sources or implementation of new methods. While these events typically impact internal migration, in the case of the U.S. Census Bureau's net international migration estimates, Hurricane Maria made landfall on the island of Puerto Rico in September 2017, resulting in mass devastation and out-migration to the mainland United States. This not only impacted residents of the island, resulting in large migration flows from Puerto Rico to the United States2, but also the quality of data typically used to measure migration patterns.
2. The previous methodology to estimate migration between Puerto Rico and the United States utilized the American Community Survey (ACS), and its counterpart, the Puerto Rico Community Survey (PRCS). However, as a result of the hurricane, these data sources yielded inadequate measures of net migration for the Vintage 2018 estimates year. This paper describes the methodology used to address this issue, integrating ACS/PRCS data with "big data," specifically incorporation of monthly Airline Passenger Traffic data (APT) from the Bureau of Transportation Statistics (BTS). While the ACS did not adequately measure out-migration from Puerto Rico to the United States in the immediate aftermath of Hurricane Maria, monthly airline data did show a mass exodus of persons from the Island to the United States during this time period. Historically, APT data has consistently shown higher net out migration from Puerto Rico to the United States than ACS/PRCS estimates. To account for this inherent difference between data sources, the revised method "blends" ACS/PRCS and APT data, taking into account these differences. The result is an estimate of the Puerto Rico population that includes the impact of Hurricane Maria. Further, we used an ARMA model to evaluate the "blended" approach, which yielded similar results, and discuss further potential use of airline data for the estimation of international migration.

II. Background

3. The Commonwealth of Puerto Rico is an unincorporated territory of the United States, located between the Caribbean Sea and the Atlantic Ocean, 1,600 km from Miami, Florida, acquired by the United States in 1898 after the Spanish-American War. It has a population of over 3 million persons, but this has been declining since 2004, primarily due to out-migration to the United States, coinciding

[1] https://www.climate.gov/news-features/blogs/beyond-data/2018s-billion-dollar-disasters-context; https://library.wmo.int/doc_num.php?explnum_id=5789

[2] While Puerto Rico is part of the United States, for the purposes of this paper, the United States is defined as territory within its 50 states.

with economic decline on the island.[3] Puerto Ricans are U.S. citizens and have the right to free movement between Puerto Rico and the United States, resulting in over 5 million Puerto Ricans living in the United States.[4] However, the U.S. Census Bureau's estimates program does not include movement of persons between the United States and Puerto Rico as part of its domestic migration estimates, but rather as part of its net international migration (NIM) component. Historically, the Puerto Rico component has been a relatively small piece of NIM, making up less than 8% of the total NIM component prior to the Vintage 2018 estimates year.[5]

4. Hurricane Maria was a large Category 5 hurricane which devastated Dominica, the U.S. Virgin Islands, and Puerto Rico in September of 2017. Moving through the Caribbean, it struck Puerto Rico as a Category 4 hurricane on September 20, 2017, resulting in extensive damage and loss of human life. Most of the island suffered from flooding, and it took almost a year before power was fully restored to the island.[6] As result of the hurricane, there was an accompanying mass movement away from Puerto Rico, primarily to the mainland United States.

5. Initial reports varied as to the size of the potential "exodus" to the United States, with the Puerto Rico governor predicting millions of Puerto Ricans flocking the United States, while other estimates ranged from 100,000 to 240,000 persons.[7] Between October 3rd and November 30th, the Florida Division of Emergency Management counted over 208,000 persons from Puerto Rico landing in Miami airports. However, these early estimates did not account for potential return migration to Puerto Rico, which was estimated to range from 135,000 to 145,000, resulting in a net out-migration of 90,000 to 93,000 persons.[8] This mass movement of persons was not readily measured in the data sources used by the U.S. Census Bureau's population estimates methodology, and thus had a potential impact on the resulting estimates.

III. Puerto Rico population estimates and data sources and the impact of Hurricane Maria

6. The U.S. Census Bureau annually produces population estimates, representing the population as of July 1st of each estimated year. Net migration from Puerto Rico not only impacts the population estimate for Puerto Rico (which can only change via births, deaths, or migration), but also for the mainland United States, as it is included as part of the national NIM component. For this decade's estimates, prior to 2018, the estimates program has utilized the American Community Survey (ACS) and the Puerto Rico Community Survey (PRCS) to estimate migration between the United States and Puerto Rico. The ACS is an annual continuous survey of the U.S. population that asks detailed information previously collected on the decennial census long form. Fully implemented in 2005, it currently surveys about 3.5 million households per year. Estimates of migration flows from Puerto Rico to the United States are based on responses to the residence one year ago (ROYA) question,

[3] Puerto Rico Report, January 7, 2013. "Puerto Rico's Population Continues to Decline," https://www.puertoricoreport.com/puerto-ricos-population-continues-to-decline/#.XVa1Hf2P4fc

[4] Ying Wang and Stefan Rayer. 2018. "Growth of the Puerto Rican Population in Florida and on the U.S. Mainland."

[5] https://www.census.gov/data/datasets/time-series/demo/popest/2010s-total-puerto-rico.html; https://www2.census.gov/programs-surveys/popest/tables/2010-2018/state/totals/nst-est2018-05.xlsx

[6] https://www.nytimes.com/2018/08/14/us/puerto-rico-electricity-power.html

[7] Center for Puerto Rican Studies. 2017. "Estimates of Post-Hurricane Maria Exodus from Puerto Rico." https://centropr.hunter.cuny.edu/sites/default/files/RB2017-01-POST-MARIA%20EXODUS_V3.pdf

[8] PEW Research Center. 2017 ."Puerto Ricans leave in record numbers for mainland U.S."; Stefan Rayer. 2018 . "Hurricane-Induced Migration: Estimating Puerto Rican Arrivals in Florida In the Aftermath of Hurricanes Irma and Maria Using Flight Passenger Data."

asking where respondents lived one-year prior to the survey. Data are collected on a continuous basis throughout the year and represent the calendar year, though movement could have occurred at any time over a 2-year period, depending on when the respondent was included in the sample, and when they actually moved. The PRCS is the Puerto Rico equivalent to the ACS and is used to measure migration flows from the United States to Puerto Rico using the same ROYA question. It is also a continuous survey, with a sample of 36,000 Puerto Rican addresses, and asks almost the same questions as the ACS (with some question wording differences).

7. ACS/PRCS data are normally released in September of the year following data collection, which coincides with our NIM estimates production cycle. For example, for our vintage 2018 estimates, 2017 calendar year ACS data were used for both our 2017 and 2018 NIM flow estimates (with 2018 flow estimates then updated with 2018 ACS data in the subsequent 2019 estimates release, and so forth). This works well when migration patterns are stable but can lead to substantial NIM revisions in the subsequent release of population estimates if patterns change drastically.

8. As a result of Hurricane Maria, field operations for PRCS data collection were suspended from October to December 2017 and did not resume until January 2018. Furthermore, the weighting procedure used for the 2017 PRCS was not adjusted to account for Hurricane Maria's impact. Vintage 2017 controls were used to adjust 2017 PRCS estimates, thus nine months of data collection were used to estimate the full year. This meant that pre-Hurricane migration patterns were extrapolated for the full 12-month period, which likely resulted in overestimation of in-migration to Puerto Rico, which would have been minimal from October to December 2017.

9. Conversely, analysis of monthly ACS data did not show a large influx of "in-migration" to the United States from Puerto Rico from September to December 2017; thus, it is likely the ACS was not picking up hurricane-related migration flows. This could have been due to a number of factors, including the late timing of Hurricane Maria during 2017 and the corresponding short-period of time to be included in the sample (October to December); the 2-month usual residency requirement to be included in the ACS sample; or even respondents' belief that their move was just temporary and they would soon return to Puerto Rico, leaving them disinclined to participate in the survey.

10. Results from the 2016 ACS/PRCS resulted in the measurement of 88,000 migrants from Puerto Rico to the United States, and 21,000 migrants from the United States to Puerto Rico, resulting in a net loss of -67,000 people for Puerto Rico. 2017 results were similar, with 97,000 migrants from Puerto Rico, and 20,000 migrants to Puerto Rico, resulting in a net loss of -77,000. The change of just 10,000 net migrants between 2016 and 2017 indicates that the 2017 ACS did not reflect much hurricane-related movement to the United States, at least to the magnitude we expected.

11. Household sample surveys like the ACS/PRCS are not designed to pick up sudden mass movements of persons, since retrospective survey-based migration data tend to "lag" actual migration events. Surveys do not measure a migration event when they actually occur, but rather measure the event when the migrant is included in the sample. This works well when migration patterns are stable, but when there are large annual fluctuations in the magnitude of movement, these will not be fully picked up until later (usually in the following survey year). The late timing of Hurricane Maria (late September) in the survey data collection cycle further exacerbated this issue. As a result, it was necessary to look for an alternative data source to enable us to measure the impact of Hurricane Maria on migration out of Puerto Rico.

IV. Alternative "Big Data" source

12. There has been a fair amount of research into the application of "big data" to measure international migration in recent years.[9] This has included research on the use of social media (Facebook location, Twitter "tweets", etc.), cell phone usage (location of where a person was when making a call vs. location of registered sim card/where calls originated vs. where calls went), advertising data, passenger flight data, and other commercial data. While utilization of these data sources to measure international migration are still in nascent form, there are still a number of issues which need to be worked out, including issues of coverage (e.g. who uses Facebook?), measurement (e.g. what is a migrant?), accuracy (e.g. do more than one person use the same cell phone?), as well as access to and cost of data, and data privacy, to name a few. In general, "big data" are currently not seen as a replacement for traditional sources of international migration data, but rather as a way to supplement and add value to pre-existing data sources.[10]

13. One type of "big data" is information collected by airlines on the number of passengers who fly between airports (origins and destinations). In the United States, flight data are compiled from monthly reports filed by over 200 commercial U.S. and foreign air carriers with the Bureau of Transportation Statistics (BTS), including both domestic and international flights. Release of annual data on international flights lags about 6 months from the end of the year, with complete international data available in the middle of June of the following year, while domestic flight data are released more frequently (lagging about 2 months). Monthly international flight data are released 3 months after domestic data. Reporting of data are for all flights (thus no sampling is involved) following Federal report guidelines which went into effect in October 2002.

14. Specifically for Puerto Rico, Airline Passenger Traffic (APT) Domestic data provide monthly information on the number of passengers flying on planes between Puerto Rico and the United States. It should be noted that APT data include information on all travelers, not just migrants, and thus include movements of visitors, tourists, business travelers, etc., who make up the vast majority of flight passengers. The logic behind its use to measure migration is that all non-migrants will be counted on both their in-bound and out-bound flights, while migrants will only be counted in one direction (unless leaving temporarily, in which case they would be counted again upon their return). The major limitation of this method is that it can only provide a number for "net" migration, with no information on total in- or out-flows, as migrants cannot be distinguished from the total number of passengers entering or leaving Puerto Rico. Further, this method is only applicable to a country or territory without any land borders, such as an island, like Puerto Rico. Total ship passenger movement to and from Puerto Rico is assumed to be minimal. Monthly tallies of net migration also reflect seasonal variation related to tourism, with presumably greater movement into and out of Puerto Rico in the summer and winter vacation months. Depending on the measurement period (e.g. a calendar year), this could lead to year-to-year fluctuations related to annual tourism trends (e.g. in a good tourist season, a high number could be counted in December, while the return of these same tourists might happen in January of the following year), though these are thought to balance out over time. Keeping these limitations in mind, the use of APT data measures movement at the actual time it occurs, unlike a survey instrument, which is a retrospective measurement of the migration event.

[9] For example, see the International Organization for Migration's (IOM). "Big Data for Migration Alliance (BD4M)," https://gmdac.iom.int/sites/default/files/big-data-for-migration-alliance-concept-note.pdf

[10] IOM. 2017. "Big Data for Migration: Uses, opportunities, and challenges," https://unstats.un.org/unsd/demographic-social/meetings/2017/new-york--egm-migration-data/Session%209/Session%209%20IOM.pdf

Thus, as will be seen, APT data were more effective for measuring net migration from Puerto Rico after Hurricane Maria than the ACS/PRCS.

1. A. APT results

15. APT data seem to better reflect the impact of Hurricane Maria on movement from Puerto Rico. Table 1 shows a large spike in the number of passengers flying from Puerto Rico to the United States during the latter months of 2017 (September to December), resulting in large net out migration, with a corresponding return of passengers to Puerto Rico in the early months of 2018, reflecting return migration. However, looking at 2018 data, this return movement (Puerto Ricans returning to Puerto Rico from the United States) quickly dropped during the early months of 2018, returning to net out-migration by April 2018.

Table 1
Monthly Net Flight Passenger Movement between Puerto Rico and the United States: 2015 to 2018

	2015	2016	2017	2018
Total Net	**-122,084**	**-108,693**	**-301,304**	**88,194**
January	-11,663	-15,749	-19,817	**66,321**
February	-2,931	-8,956	3,228	**14,128**
March	-20,427	-10,452	-10,566	1,981
April	-31,010	-28,798	-29,671	-8,264
May	-28,130	-36,394	-24,606	-8,949
June	-7,266	1,624	8,287	6,424
July	-2	-1,736	-3,436	-5,213
August	-34,542	-21,861	-28,766	-10,179
September	-18,014	-15,816	**-43,144**	-16,017
October	2,005	-6,346	**-93,177**	1,581
November	-5,398	1,227	**-43,626**	3,984
December	35,294	34,564	**-16,010**	42,610

Source: U.S. Bureau of Transportation Statistics, Airline Passenger Traffic Data.

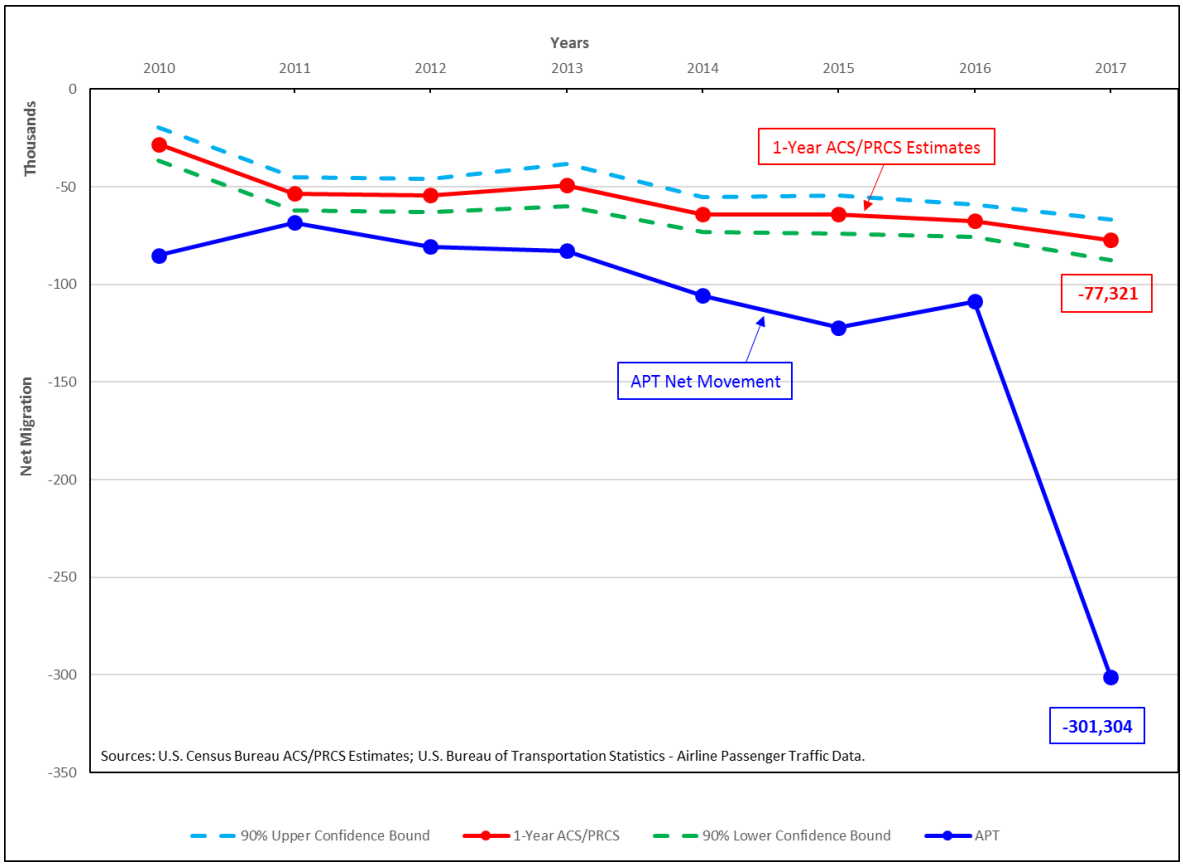
16. Further looking at Table 1, we see that for 2015 and 2016, net passenger movement out of Puerto Rico was -122,084 and -108,693, respectively, but in 2017 this number almost tripled to -301,304 persons, reflecting the impact of Hurricane Maria. Focusing on monthly movements, prior to Hurricane Maria (September 2017), net movement between the United States and Puerto Rico followed relatively stable patterns, with more passengers leaving than entering Puerto Rico, except for some summer or winter months (June and December, in particular). This is thought to correspond with seasonal flight patterns, with more tourists coming during summer and winter months, as well as return visits by Puerto Ricans living in the United States during vacation periods. For 2017, the pattern changes however, as we see the first surge in passengers leaving Puerto Rico in September (-43,144), peaking in October (-93,117), and continuing into months when flight passengers typically enter Puerto Rico (-43,626 in November and -16,010 in December). 2018 is also an anomaly, as we see a large number of return movement to Puerto Rico in January (66,321), February (14,128) and even positive movement in March (1,981). Movement seems to normalize to prior patterns thereafter,

with net out-movement in April and May, and positive net movement in June and later months (October to December). As such, it is clear that movement to and from Puerto Rico from September 2017 to February 2018 was especially impacted by Hurricane Maria, while 2017 ACS/PRCS data did not reflect this impact.

V. ACS vs APT comparisons

17. As seen in Figure 1, prior to 2017, ACS and APT data tended to follow similar patterns, with APT data consistently showing more net out-movement than ACS net out-migration. Taking ACS sampling variation into account, this was true of all years except 2011. The effect of Hurricane Maria is very visible in the 2017 results, as the ACS did not reflect a huge out-migration from Puerto Rico during this year.

Figure 1
Net Puerto Rico-to-United States Migration: 2010 to 2017



18. Table 2 provides the same information as Figure 1, but also gives a sense of the difference in gross movement (total in- and out-migration or movement) between the two data sources. Flight data between Puerto Rico and the United States record about 8 million moves (flight passengers) per year, while ACS/PRCS ROYA migration data count about 100,000 persons who changed usual residence (gross migration). Given flight information is primarily made up of non-movers, these differences are to be expected.

Table 2
Comparison of APT and ACS/PRCS Annual Migration Flows between the United States and Puerto Rico: 2010 to 2017

Years	Air Passenger Traffic Data			ACS/PRCS Annual Estimates		
	Ins	Outs	Net	Ins	Outs	Net
2010	3,700,263	3,785,500	-85,237	31,732	59,885	-28,153
2011	3,534,030	3,602,480	-68,450	22,649	76,218	-53,569
2012	3,672,341	3,753,135	-80,794	20,044	74,500	-54,456
2013	3,665,767	3,748,616	-82,849	24,652	73,846	-49,194
2014	3,702,073	3,807,775	-105,702	19,771	83,844	-64,073
2015	3,785,132	3,907,216	-122,084	24,762	89,000	-64,238
2016	3,951,359	4,060,052	-108,693	21,196	88,676	-67,480
2017	3,611,199	3,912,503	-301,304	20,167	97,488	-77,321

Sources: U.S. Bureau of Transportation Statistics, Airline Passenger Traffic Data; US Census Bureau ACS and PRCS estimates.

19. As already discussed, APT data has recorded higher net out-migration than ACS for almost all years, findings which are consistent with many forms of administrative data, which tend to produce larger numbers than survey-based migration estimates.[11] While more research is needed to understand these differences, they are likely due to inherent differences between administrative and survey-based data, including factors such as coverage, volume of movement, accuracy of recordings, measurement at time of move vs. post facto measurement, sampling variability, etc. Given our United States-to-Puerto Rico NIM estimates for years prior to Vintage 2018 have been based on ACS/PRCS flow data, we wanted to keep any new estimation method as consistent as possible with our prior method, yet take into account the more accurate data provided by APT measuring the impact of Hurricane Maria. Replacing ACS data with APT data for the entire period was considered but deemed too late in the decade to fully implement, especially when questions remain about the use and quality of flight data. More research on the validity of flight data, as well as how they are collected and measured, is needed, but this will be an area for future work.

VI. Methodology used to combine ACS and APT estimates

20. The decision was made to integrate results from both ACS/PRCS and APT data sources, with a desire to make the data outputs as comparable as possible. In effect, ACS/PRCS and APT net migration results were blended to adjust APT net migration estimates to reflect pre-2017 ACS/PRCS-to-APT trends. The APT figure was adjusted since APT data were seen to more accurately reflect net migration after Hurricane Maria, as opposed to the ACS/PRCS, which failed to adequately measure

[11] UNECE. 2016. *Handbook on the use of Administrative Sources and Sample Surveys to Measure International Migration in CIS countries.* http://www.unece.org/fileadmin/DAM/stats/publications/2016/ECECESSTAT20162_ENG_web.pdf

its impact. Essentially, we were attempting to produce a new "ACS"-based estimate for 2017 which takes the hurricane into account.

21. To make the two data sources as comparable as possible, we compiled monthly flight data for the 2017 calendar year to coincide with the ACS/PRCS estimation period.[12] We also limited flight information to domestic flights between the United States and Puerto Rico, excluding other international flights, again to make the APT universe consistent with the ACS/PRCS. The final method applied a simple ratio method, using the ratio of ACS/PRCS-to-APT net migration results over a two-year period: 2015 to 2016. We also investigated using ratios based on longer time periods (as far back as 2012) but elected to go with a shorter time period to more accurately reflect recent relationships between data sources. The calculated ratio was applied to the APT Puerto Rico-United States net migration figure measured for calendar year 2017, to remain methodologically consistent with our previous ACS/PRCS-based estimates.

VII. Results

22. As seen earlier in Table 1, the 2017 ACS/PRCS measured -77,321 net migration from Puerto Rico, which did not reflect the impact of Hurricane Maria. Meanwhile, as seen in Table 2, the APT measured -301,304 net migrants from Puerto Rico during calendar year 2017, with the vast majority of movement (-195,957) occurring during the months of September to December, reflecting post-Maria out-migration from Puerto Rico to the United States.

23. As seen in Table 3 below, ACS/PRCS net migration results were on average lower by a factor of 0.5735 than the APT during the two-year period of 2015 and 2016 (pre-Hurricane Maria patterns). Thus, to get an equivalent ACS/PRCS figure for 2017, the 2017 APT number (-301,304) was multiplied by the .5735 ratio to yield an estimate of -172,799 persons. This is equivalent to applying 2017 ACS/PRCS data to the vintage 2018 estimate year, thus consistent with the methodology used for previous Puerto Rico to the United States net migration estimates.

Table 3
Ratio Method of ACS/PRCS to APT for Years 2015 to 2017

Net Migration	2015	2016	2017
ACS/PRCS	-64,238	-67,480	***-172,799***
APT	-122,084	-108,693	-301,304
Ratio	0.52618	0.62083	
Avg. Ratio	**0.5735049**		

Sources: U.S. Bureau of Transportation Statistics, Airline Passenger Traffic Data; US Census Bureau ACS and PRCS estimates.

A. Final adjustment

24. The initial application of the ratio method to 2017 APT calendar year data resulted in net out-migration of -172,799 persons for 2017. However, as you may recall from Table 1, according to 2018 APT data, there was a corresponding return migration to Puerto Rico in the early months of 2018, particularly in January, slowing down in February, and returning to negative in April. Since our Vintage 2018 population estimates represent the population as July 1, 2018, it was decided to take

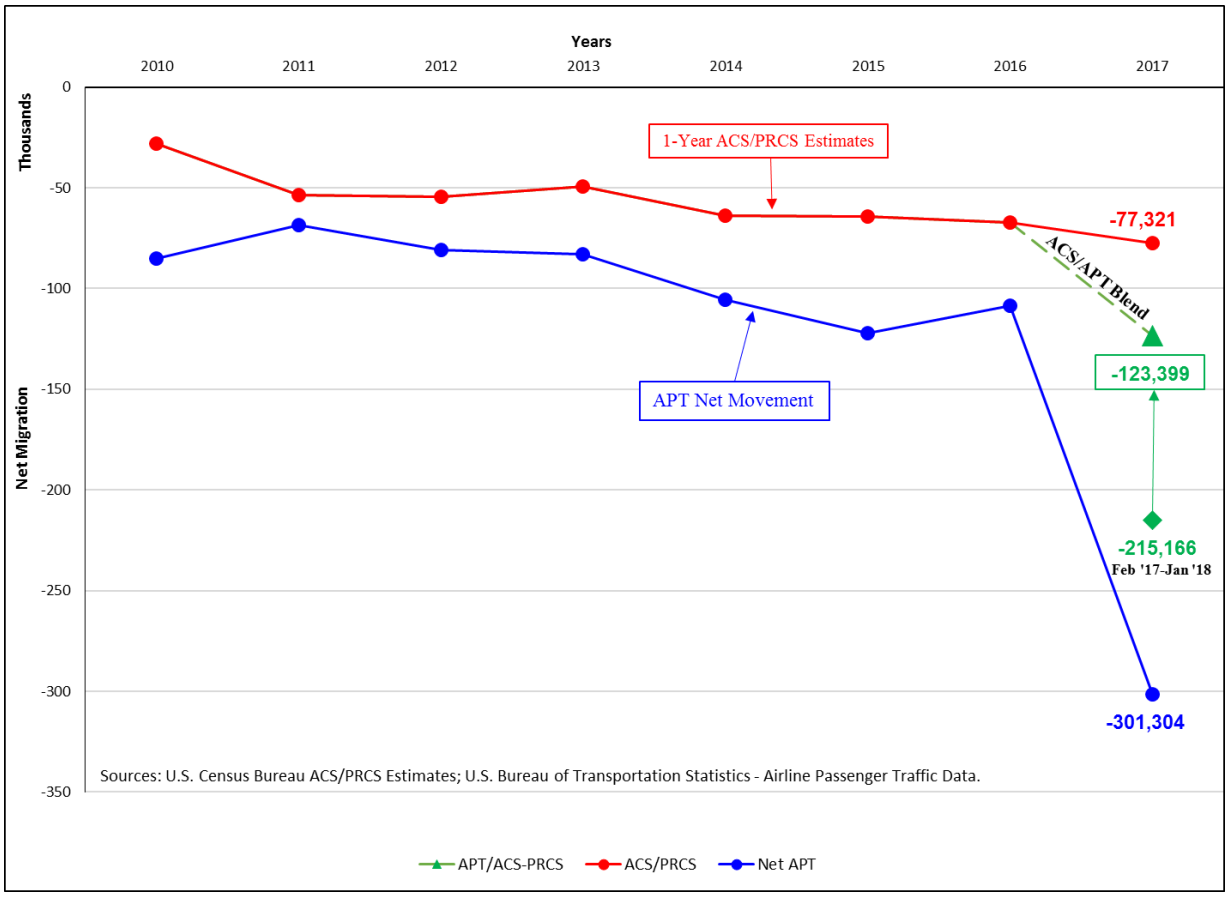
[12] This differs from the Vintage 2018 estimates year, which covers June 31, 2017 to July 1, 2018.

into account some of this return migration to Puerto Rico, so as to not overstate the impact of net migration out of Puerto Rico due to Hurricane Maria.

25. Our method was adjusted as follows. In order to account for January return migration, we used the 12-month APT time period from February 2017 to January 2018 prior to applying our two-year ratio, to make the time period as ACS-equivalent as possible, while still taking into consideration return migration to Puerto Rico. Shifting our time period one month helped account for return migration, yet also kept most months (11 of 12) within the ACS/PRCS-equivalent 2017 calendar year.

26. This modification resulted in an APT-Puerto Rico-United States net migration figure of -215,166, which when adjusted by the APT-ACS ratio, yielded a final figure of -123,399 net migration from Puerto Rico to the United States. The final time series results are reflected in Figure 2. This method takes APT data from approximately the same time period as the ACS (shifted one month), adjusts this figure as if it were the ACS based on trends over the past two years (e.g. the ACS were able to measure this sudden migration event) while also accounting for return migration early in 2018.

Figure 2
Net Puerto Rico-to-U.S. Migration: 2010 to 2017



B. ARMA model

27. The ratio method was sufficient for adjusting estimates when faced with a significant time constraint. We later looked at more sophisticated modeling techniques to see if we could improve our "blended" estimates. One approach was to conduct a statistical analysis of the time series, using an autoregressive-moving-average (ARMA) model to predict a future value in the time series, using a Box-Jenkins method. After testing out different model iterations, it was decided that the most complex model which we could use to fit the data was the simplest ARMA (0,0) model. This model predicted a difference between the ACS and APT for 2017 of 38,950, which resulted in a predicted Puerto Rico migration of -262,350 for 2017 from the ACS-adjusted-to-APT data time series. The margin of error for this prediction was 10,700. The result from this method was relatively close to our initial unadjusted estimate of -215,166, using the simpler ratio method, and thus improved our confidence in the ratio method. More research into possible modeling applications is planned for the future.

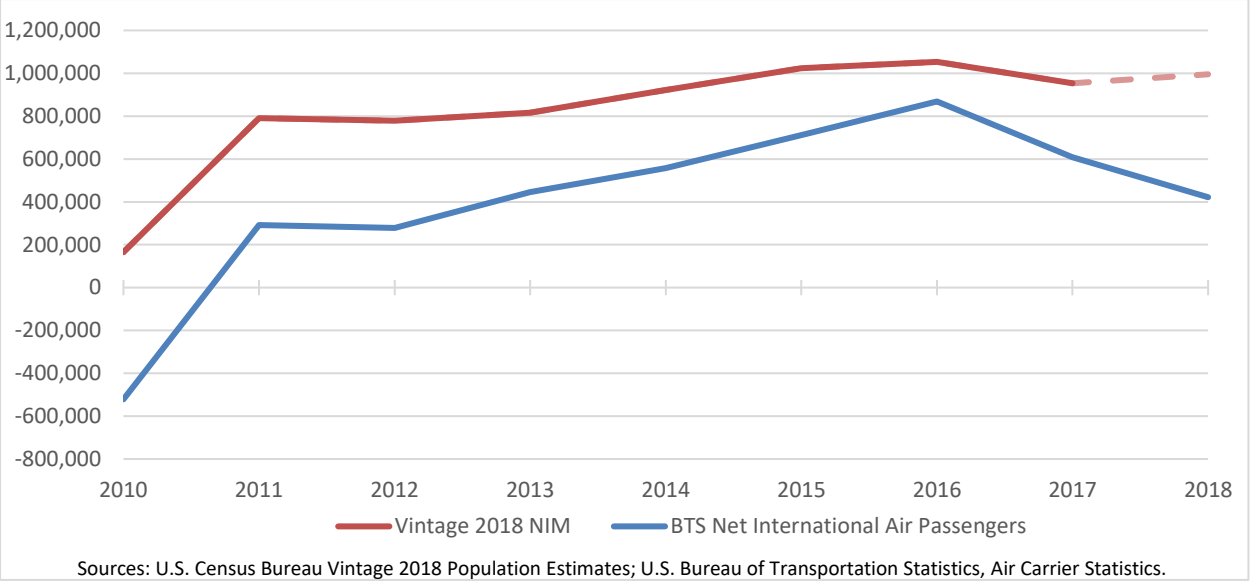
VIII. Vintage 2019 estimates and future work

28. After making our adjustments for post-Hurricane Maria Puerto Rico migration, we were cognizant that we would likely need to readjust data for the 2019 estimates year, as ACS/PRCS input data would likely lag current migration patterns. As expected, 2018 ACS/PRCS data did pick up the effect of Hurricane Maria, with a net out-migration of 112,000 between Puerto Rico and the United States. However, as seen earlier in Table 1, 2018 APT data showed a net migration gain to Puerto Rico of 88,000 persons, mostly due to return migration in the earlier part of the year. As a result, for our V2019 estimates, we will need to once again "blend" both ACS and APT data, to take into account additional return migration to Puerto Rico in 2018 and the ACS "lag" in Hurricane Maria-related out-migration measurement.

29. For next decade's estimates, we will pursue additional research to determine the viability of replacing ACS/PRCS net migration estimates with a flight data-based approach. It will likely still be necessary to use the ACS/PRCS to determine the characteristics of movers, as well as to calculate the size of migration flows to and from Puerto Rico, as flight data can only provide a net figure. We must also come to a better understanding of the limitations of flight data, why it differs from ACS data, and answer questions about some of its data peculiarities (e.g. lack of seasonality in gross movements), before we can fully implement this new methodology. In any event, some type of "data integration" will likely still be needed, perhaps using a more model-based approach, as opposed to a simple "ratio" method.

30. We have also begun looking at international flight data for the United States. While we are aware that this measures only a portion of international movement, and excludes land border moves between the United States and Canada and Mexico, initial evaluation of flight data has been positive, as it can provide a possible benchmark to evaluate trends discovered in our current NIM methodology. Figure 3 shows a time series comparison of our NIM estimates (primarily ACS-based) and net international air passenger data.

Figure 3
Vintage 2018 Net International Migration Estimates and Net International Air Passengers (In Estimates Years)



Sources: U.S. Census Bureau Vintage 2018 Population Estimates; U.S. Bureau of Transportation Statistics, Air Carrier Statistics.

31. Interestingly, flight data and NIM estimates track relatively well, in terms of net migration trends. As expected, the level of NIM estimates are higher than flight data (which are only a portion of all cross-border moves), but trends between the two data sources tend to move in the same direction. Most importantly, it might be possible to use flight data to project our final year of NIM estimates, which are currently based on data which are one year behind the estimates year, and updated in the subsequent year as new input data are received. For example, as seen in Figure 3, for our Vintage 2018 NIM estimates, we use the 2017 ACS to project our 2018 estimate since it is the most recent data available (seen in the dotted line in Figure 3). 2018 BTS data show a marked decrease in net international data between 2017 and 2018. For our internally simulated Vintage 2019 NIM estimates, we found a 17% decrease in NIM between 2018 and 2018, which tracks in the same direction as the BTS figure (a 31% decrease). Since BTS data are released earlier than the ACS (released monthly with a six-month lag, with annual data available in July of the following calendar year), it could be possible to use those numbers to help project our estimates time series more accurately.

IX. Conclusions

32. While the application of "big data" is still limited from the perspective of the United States for producing net international migration estimates, we are looking into alternative sources to help improve, or at least benchmark, NIM estimates produced via our current methodology. In the case of an island like Puerto Rico, with limited border crossings, we will continue to investigate the viability of using flight data, alone or in combination with other sources, to estimate migration. Our current survey-based methodology tends to be effective when migration patterns are relatively stable, but will lag actual migration events when there are sudden changes in migration patterns, either due to natural disasters, or even due to significant national policy changes. In any event, integration of multiple data sources will play a prominent role in the future production of international migration estimates and will continue to be pursued and incorporated into our estimates program.