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Banks versus Hurricanes: A Case Study of Puerto Rico after Hurricanes Irma and Maria

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FEDERAL RESERVE BANK of NEW YORK

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Abstract

We study Puerto Rico's experience after the severe hurricane season of 2017 to better understand how extreme weather disasters affect bank stability and their ability to lend. Despite the devastation wrought by two category 5 hurricanes in a single month, we find relatively modest and transitory impacts on bank performance with no evident decline in lending capacity. We discuss various mitigants that help limit bank exposure to extreme weather and whether these mitigants may be vulnerable given the potential for more severe and more impactful climate events.

JEL classification: G21, Q54
Keywords: climate change, physical risks, hurricanes, banks, Puerto Rico

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I. Introduction

Global climate warming has garnered broad scientific consensus (see, e.g., NASA (2022) for broad-based scientific perspectives on the topic), and climate financial risk – climate change's impact on the financial institutions, financial markets, and the financial economy – is an active area of study from policy, academic, and industry perspectives. Banks, in particular, have clear financial incentives to protect against climate-related losses from climate outcomes' negative effects on their customers, clients, and counterparties, the collateral that is used to secure their loans, and their own business activities. Additionally, many contractual and market mechanisms exist for banks to protect their financial interests. However, severe climate events may occur that are far beyond the worst expected outcomes that banks plan for or protect against, so it is an empirical matter whether banks are able to implement sufficient safeguards to protect themselves against unexpectedly severe climate-related events.

We use Puerto Rico's experience during the devastating hurricanes of 2017 as a case study to better understand the effects of severe weather events on geographically vulnerable areas and the banks that lend in those areas. Puerto Rico (PR) was extremely vulnerable even before Maria struck. Its economy and banking sector had contracted for nearly a decade and its water and electrical infrastructure was fragile due to chronic fiscal constraints on investment and maintenance. Compounding matters, Hurricane Irma dropped a foot of rain in Puerto Rico just two weeks before Maria, leaving the island waterlogged and prone to mudslides (a peril associated with Puerto Rico hurricanes). Given those challenging initial conditions, Maria might constitute a worst case for studying bank resilience against extreme weather.[1]

The destruction and disruption from Maria were immense. Nearly 80 percent of the island's electrical grid was destroyed and most of the island 3.4 million residents lost power for months. Thousands of homes were damaged or destroyed. Flash floods caused landslides and destroyed many bridges. FEMA estimated damages from Maria at $90 billion, the third costliest in U.S. history. The combined damages from Irma-Maria nearly exceeded the island's entire annual GDP of around $104 billion in 2016.

Despite the devastation, we find that financial losses to banks were relatively minor and transitory. We formally identify the effects using difference-in-difference analysis, where we compare how banks headquartered in Puerto Rico fared relative to a control group of US banks on the mainland. We find higher loan delinquency rates, but the impact was modest and short-lived. Banks' capital and income were not significantly affected, nor was loan growth.

Our results are consistent with previous research on hurricanes risk to banks. Brei, Mohan, and Strobl (2019) find that banks in eastern Caribbean islands experienced deposit withdrawals after hurricanes, but no deterioration in loan defaults or capital. Gallaher and Hartley (2017) find that consumer loan delinquencies rose only briefly and modestly after Hurricane Katrina struck New Orleans in 2005. A study of U.S. weather disasters more generally since 1995, Blickle, Hamerling, and Morgan, (2022) finds small or insignificant effects on bank performance. Du and Zhao (2020) compare the residential

[1] According to Germanwatch Global Climate Risk Index (2021), Puerto Rico ranked highest of 180 countries/ territories based on the number of severe weather events, fatalities, and economic losses from 2000 to 2019, most of which are hurricane related. Maria also badly damaged Dominica and St. Croix.

mortgage loan performance of Hurricanes Harvey and Maria in 2017, and highlight initial conditions, namely home prices, as well as federal assistance.

We explain the variety of protections that the banks use to insulate themselves from more sizeable losses, and we explore whether these protections may be vulnerable in future severe climate events, given the potential for more severe and more impactful climate events, as broadly predicted by climate scientists. Prior research identifies a variety of risk mitigants to the banks' credit exposures, including banks' underwriting standards, homeowners' insurance that protects the value of the collateral in the case of home mortgages, and governmental emergency assistance after a natural disaster, such as FEMA disaster assistance in the United States. An, Binder, Biswas, Dice, and Hossain (2022) measure both gross and net effects of natural disasters, and find that "Historically, gross damages of most severe weather events (Katrina, Harvey, Sandy) reach up to 127 basis point of banks' outstanding loan balances," but that "Bank damage exposures reduce to 1-6 basis points for insured disasters and 6-24 basis points for uninsured disasters."

The remainder of this paper is organized as follows. **Section II** reviews the climate science of severe weather affecting Puerto Rico, summarizes historical losses from past events, and details what climate science says about the riskiness of future severe weather affecting Puerto Rico**.** **Section III** summarizes the initial conditions – the economic and financial environment in Puerto Rico before Maria and Irma. **Section IV** reports on banks' financial performance around the Irma and Maria Hurricanes, both at the bank level and at the asset (mortgage)-specific level. **Section V** delves more deeply into the range of risk mitigants that resulted in relatively minor financial impacts on banks in Puerto Rico, despite the sizable economic damages from the storms. **Section VI** concludes with certain perspectives on how resilient the historical risk mitigation arrangements may be to future climate developments.[2]

II. Backdrop and Motivation: Climate Science – Historical Storms and Translation to Losses

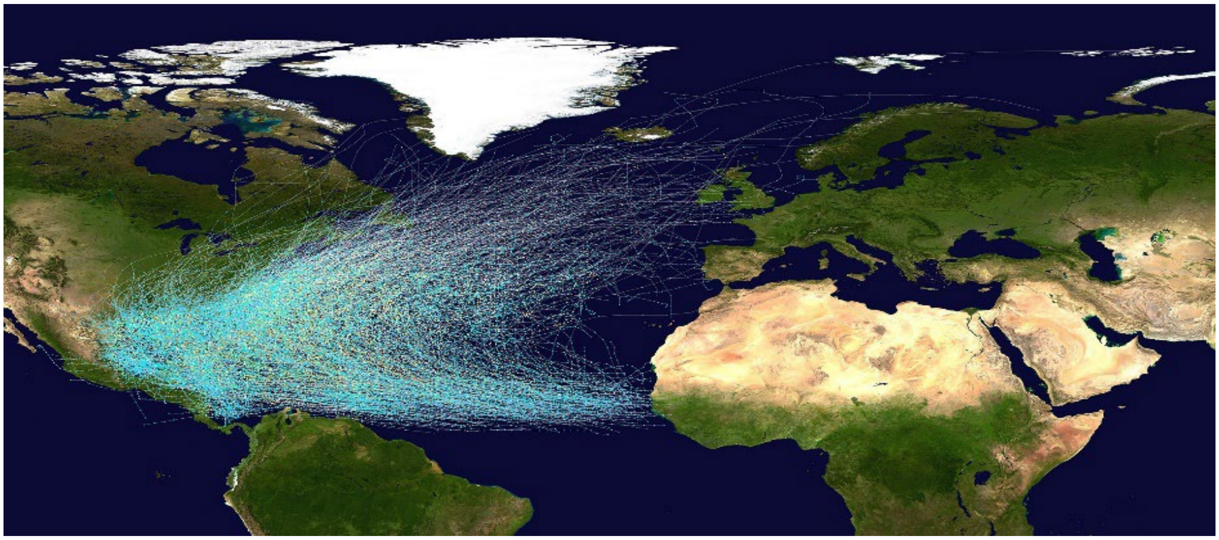
II.a Historical severe weather events in Puerto Rico

In Puerto Rico, weather-related disaster declarations have occurred on a yearly basis since 2001, which include events related to floods, droughts, tropical storms, and winter swells. Of these, the most frequent and damaging extreme events are tropical cyclones (TC) (hurricanes and tropical storms). FEMA data show that since 1955 there have been 45 disasters declared by FEMA in Puerto Rico, and 28 of these (62%) have been severe storms and hurricanes. There have also been 9 (20%) flood incidents, but most are related to storms and heavy rains, and 10 of the storms brought significant mud/ landslides.

[2] This case study parallels work performed in 2022 across the Federal Reserve System, referred to as the Climate Flow of Risk Sprint (CFoRS), which looked at a set of physical climate-related perils that would affect bank lending performance across the United States. Different Federal Reserve efforts focused on perils that would be particularly pertinent in different geographical regions of the country. Dennis (2022a, 2022b) studied the vulnerability of households, banks, and insurers to sea level risk and hurricanes in the Miami region; Hatz, Jorgenson, Oppedahl, and Peters (2022) studied the effects of both droughts and floods in midwestern U.S. agriculture; the Federal Reserve Bank of San Francisco (2022) studied the effect of wildfire risk on non-conforming mortgages in the Greater Los Angeles area; Bell, Grover, Karp, Kim, Marshall, McCord, Norris, and Olayvar (2022) studied flood risks in rural North Carolina; and Collins-Thompson (2022) studied Boston and commercial real estate. This study focuses on hurricane risks to banks that lend in Puerto Rico.

Since 1960, the Caribbean overall has experienced 264 hurricanes which account for 95% of the total damages from all natural disasters and for the vast majority of extreme rainfall events and extreme sea levels experienced in the region (Burgess, Taylor, 2018). The island is squarely in "Hurricane Alley," the swath of the North Atlantic where hurricanes are endemic, as shown in **Figure 1**.

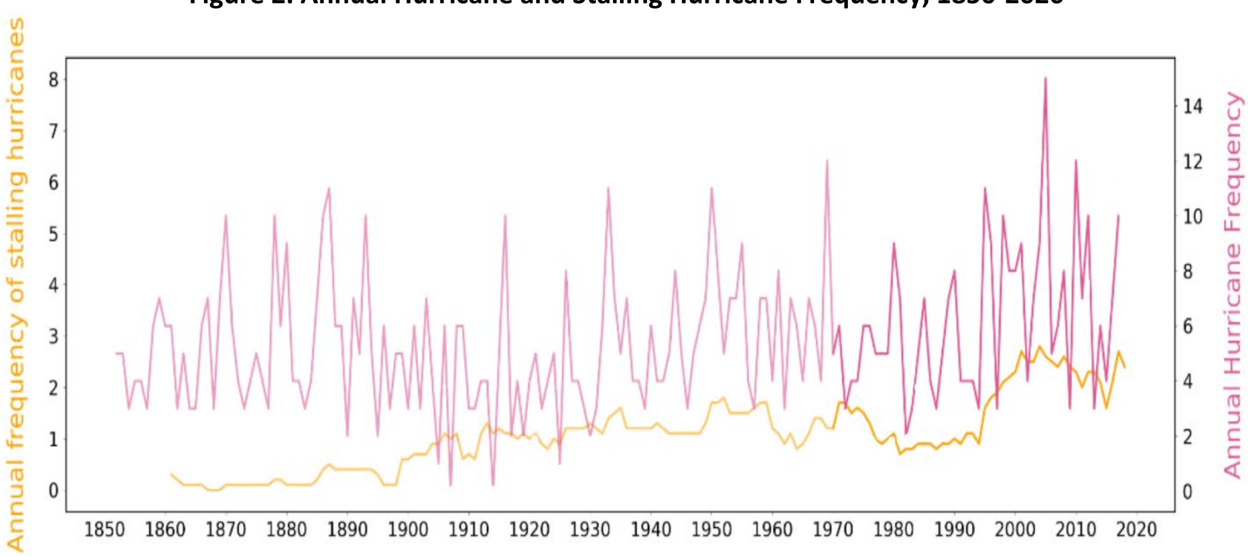
Figure 1. Hurricane Alley



Source: created using User:jdorje/Tracks by Nilfanion on 2006-08-05 using data from the National Hurricane Center. https://commons.wikimedia.org/w/index.php?curid=1023164

Figure 2 shows the frequency of hurricanes in the Caribbean going back nearly 200 years and confirms the observed increase in hurricane frequency.

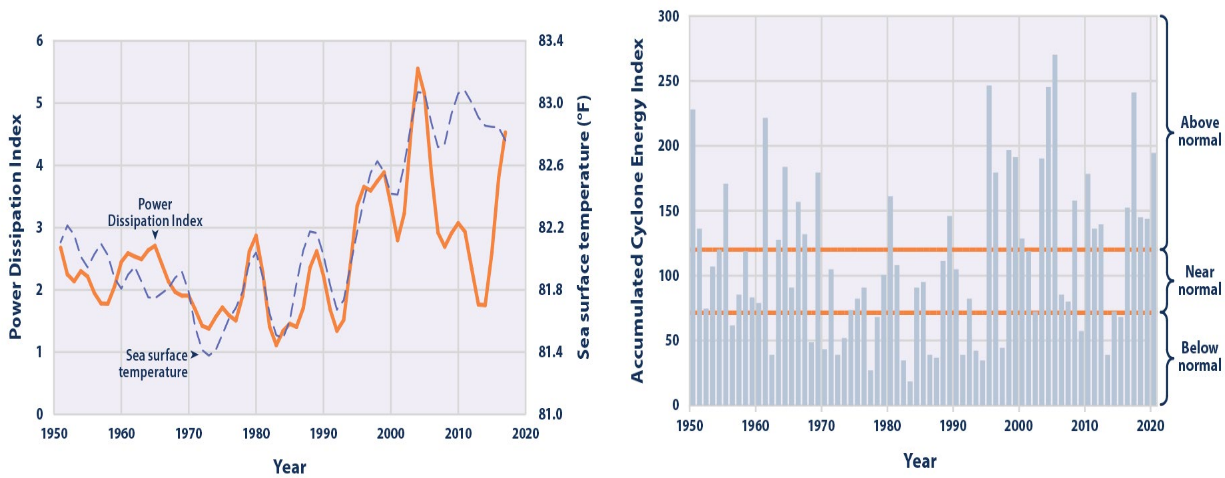
Figure 2. Annual Hurricane and Stalling Hurricane Frequency, 1850-2020



Source: Vosper, Mitchell, Emanuel (2020)

Two measures of hurricane intensity in the North Atlantic are shown in the **Figure 3** below. Both indices reflect hurricane frequency, power, and duration. The power dissipation index (PDI), the orange line at left, closely tracks sea surface temperatures (hurricanes need water temperatures above 79 Fahrenheit to form). The accumulated cyclone energy (ACE) index is shown on the right. Both metrics appear to show a growing intensity of TC seasons since 1950, which correlates with the increase in sea surface temperatures.

Figure 3. North Atlantic Tropical Cyclone Activity – PDI & ACE, 1950–2020

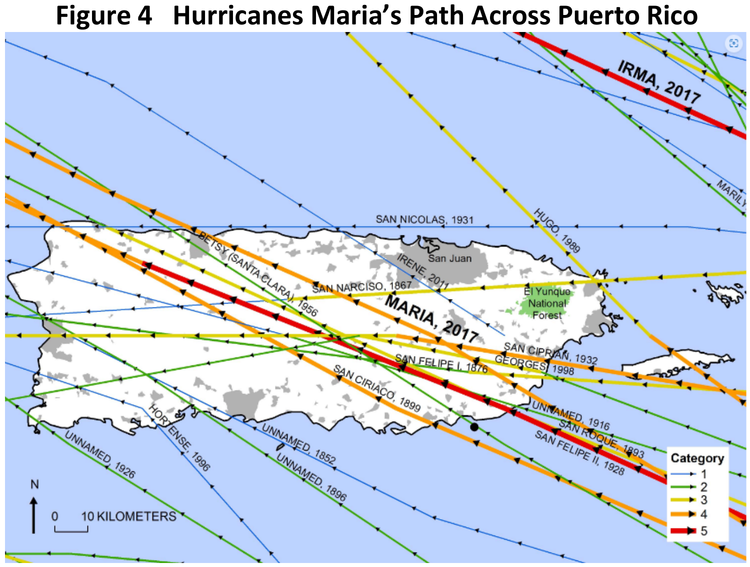


Source: [EPA – Climate Change Indicators]()

II.b Hurricane Maria

Maria touched land on the southeast part of Puerto Rico and then travelled northwesterly across the island (see **Figure 4**).

Figure 4 Hurricanes Maria's Path Across Puerto Rico



Source: US Geological Survey website (2022)

Maria stands out relative to prior storms in terms of intensity, rainfall, wind, and damage.

- Intensity: As a category 5 storm with max wind speed of 175 mph, it was the most intense to strike on the island since the 1928 San Felipe Segundo hurricane. Hurricane Maria was a 1 in 115-year extreme rainfall event for Puerto Rico.

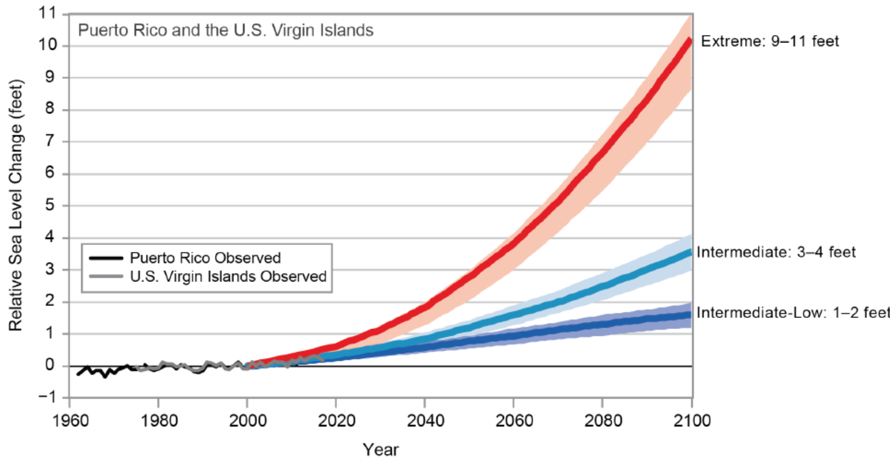
- Rainfall: Out of 129 storms that impacted Puerto Rico since 1956, the extreme rainfall associated with Hurricane Maria had the largest maximum daily precipitation—66% higher mean total rainfall than Hurricane Georges (the previous most damaging hurricane). The damage caused by the heavy rains was exacerbated by Hurricane Irma, which had drenched the ground with rain two weeks earlier. During Hurricane Maria severe flash flooding occurred in many inland locations. 30 rivers (13%) reached major flood stage, and 13 of those were at or above record stages. Many bridges were destroyed. US Geological Survey (USGS) evaluated hundreds of the more than 70,000 landslides brought on by hurricane Maria.
- Wind: Hurricane Maria knocked down 80 percent of Puerto Rico's utility poles and all transmission lines, resulting in the loss of power, cell phone service, and municipal water supplies to essentially all of the island's 3.4 million residents. Across the island, many buildings suffered significant damage or were destroyed. Thousands of homes were heavily damaged or destroyed—the majority low-rise wood-framed buildings that collapsed from high-velocity flood forces or high wind pressures. Strong winds frequently penetrated roofs and windows allowing damaging rainfall to penetrate structures.
- Damage: FEMA estimated damages from Maria at $90 billion, the third costliest in U.S. history. The combined damages from Irma-Maria nearly exceeded the island's entire annual GDP of around $104 billion in 2016. Damages caused by Hurricanes Irma and Maria prompted a humanitarian crisis in the U.S. Caribbean by causing the collapse of the region's main energy, water, transport, and communication infrastructure.

II.c.1 Future Hurricane Risks Facing Puerto Rico

Rising sea levels leads to higher storm surges and more destructive hurricanes, all else equal. Relative sea levels in Puerto Rico have risen by about 0.08 inches (2 mm) per year on average along, and the trend has been accelerating since the early 2000s. **Figure 5** illustrates potential sea level rise under three scenarios for greenhouse gas concentrations. The extreme scenario corresponds to a worst case within the IPCC highest emissions scenario (RCP 8.5).[3] The Intermediate and Intermediate Low (Net Zero) scenarios roughly correspond to RCP 4.5 and RCP 2.6. Projected increases in sea level, average TC intensity, and TC rainfall rates will each generally act to further elevate future storm surge risk. Of the various influences on surge risk, climate scientists are most confident that sea level rise over the coming century will lead to higher average storm inundation levels for TCs that occur, assuming all other factors equal.

[3] Climate scientists develop different climate scenarios based on levels of greenhouse gas (GHG) concentration in the atmosphere. These scenarios are typically indicated by a numeric representative concentration pathway (RCP) and overall global temperature increase vs. pre-industrial levels. Categories of NGFS scenarios commonly used by the financial industry are derived from three IPCC scenarios: Orderly Transition (1.4-1.6°C, RCP 2.6), Disorderly Transition (1.4-1.6°C, RCP 2.6), and Hot House (2.6-3°C, RCP 6).

Figure 5. Observed and Projected Sea Level Rise



Source: U.S. Global Change Research Program: IPCC Fourth National Climate Assessment

Scientists cannot yet make claims with a high level of confidence about long-term trends in the frequency of all TCs. But according to IPCC Sixth Assessment Report (2021),[4] it is likely that the percentage of major TCs—those reaching categories 3 to 5—increased over the last four decades. Scientists are confident in saying that there will be more frequent storms in the highest intensity categories of 4 and 5.

II.c.2 Vulnerability of Puerto Rico to sea level rise and severe weather events

The vulnerability of property is a function of the particular construction methods employed and property location, which are often driven by economic considerations and market availability. Commercial entities and residents with greater financial means tend to choose concrete buildings in developed neighborhoods that have been designed and built by professionals following local building code. Unfortunately, Puerto Rico's ongoing economic difficulties have left 40-50 percent of the Commonwealth's residents living in poverty, and many residents live in informal wood-framed buildings on hillsides or floodplains.

FEMA recently updated its flood zone maps, indicating which areas are considered at risk of a flood every 100 or 500 years (1% and 0.2% risk zones, respectively). According to a 2019 CUNY Hunter study, approximately 15% (488,560) of Puerto Rico's population resided in the 100-year floodplain; and 19% (624,414) of the population lived in a combined 100- and 500-year floodplain. The map in **Figure 6** illustrates the FEMA current and proposed 100-year flood zones. The proposed updates to these flood zone maps still have not been finalized as of late 2022, as the process to formalize and adopt these maps is laborious and time-consuming. The time delays in formally updating flood zone maps can cause unintended risk-taking, as homeowners or insurance providers who rely on outdated maps may underestimate flood risk.[5]

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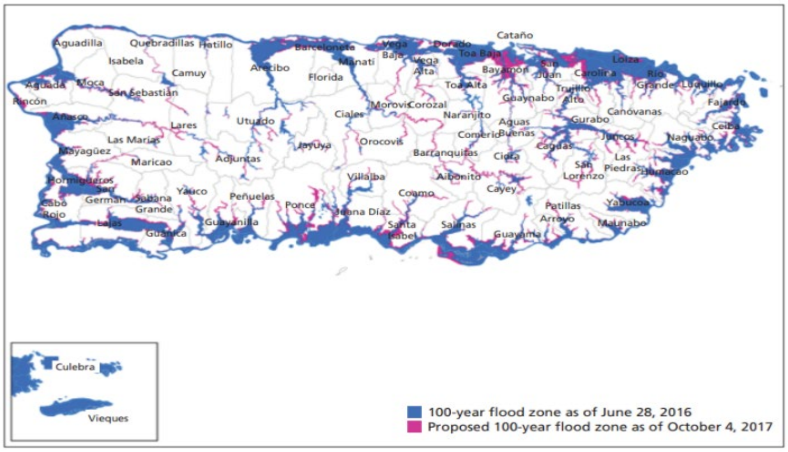
[4] https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-11/. The projections in this report draw from a 2020 World Meteorological Society (WMO) assessment report which aggregates a number of leading studies and normalizes results under an RCP 8.5 scenario.

[5] *The New York Times* has reported that delays of official FEMA flood zone maps has given rise to broader reliance on private-sector modeling of flood zones, such as by those of First Street Foundation; see New Data Reveals

Figure 6. FEMA Current and Proposed 100-year Flood Zone Map for Puerto Rico



Source: HSOAC/RAND, After Hurricane Maria (2020)

II.d Predicted Hurricane Damages

The high percentage of coastal areas relative to the total island land area means that a large proportion of the region's people, infrastructure, and economic activity are vulnerable to sea level rise, more frequent intense rainfall events and associated coastal flooding, and saltwater intrusion. High levels of exposure and sensitivity to risk in the region are compounded by a low level of adaptive capacity, due in part to the high costs of mitigation and adaptation measures relative to the region's gross domestic product, particularly when compared to continental U.S. coastal areas. For example, the IMF[6] estimates that while public adaptation costs to climate change will grow to approximately 0.25% of global GDP in coming decades, for small island nations exposed to tropical cyclones and rising seas that number could reach 20% of GDP.

Mejia (2016) estimates the impact of climate change on hurricane damage in the Caribbean by constructing a dataset that combines a detailed record of TCs' characteristics with reported damages. The paper estimates that the average annual hurricane damages in the Caribbean will increase between 22 and 77 percent by the year 2100, in a global warming scenario of high CO_2 concentrations and high global temperatures. Burgess and Taylor (2018) estimated annualized damages of approximately $824 million (2005 USD), or 1% of GDP for the Caribbean over the historical period 1964 to 2013 and predicted that annual normalized damages may potentially increase to at least $1.4BN for 1.5 °C and even higher damages at 2°C.

III. Economic and Financial Conditions Before Maria

III.a Economic Conditions

Hidden Flood Risk Across America - The New York Times (nytimes.com). The private-sector flood maps reveal heretofore "hidden" flood exposures.

[6] https://www.imf.org/en/Blogs/Articles/2022/03/23/blog032322-poor-and-vulnerable-countris-need-support-to-adapt-to-climate-change

Well before the “Great Recession” hit the U.S. economy in 2008, a deep and protracted economic downturn was already well underway in Puerto Rico. From 2006 to 2017, Puerto Rico’s population fell by 11%, GDP fell by 10%, and employment fell by 17%. As a result of this out-migration and protracted decline in its tax base, exacerbated by a lack of transparency in budgeting, Puerto Rico developed a full-blown fiscal crisis, which did not become widely apparent until 2014.

In the years leading up to Maria, Puerto Rico’s power and water infrastructure—already dilapidated and fragile prior to the fiscal crisis—deteriorated further, as a result of budget cuts and lack of maintenance. Even before the storm, extensive power outages had already darkened most of the island occasionally. When Maria struck, Puerto Rico would face the most extensive blackout, in terms of magnitude and duration, in U.S. history.

One structural challenge in Puerto Rico is its high poverty rate—higher than in any of the 50 states, and roughly twice the national average. Median household income is just $21,000, just about one-third of the mainland level. One contributing factor is its historically low labor force participation rate: less than half of its adult population is either working or looking for work. Some “missing workers” may actually be employed in the island’s informal economy.

Another relevant structural factor relates to homeownership. While homeownership rates in Puerto Rico are comparable to the mainland U.S., mortgage financing is much less common.[7] Only 41% owner occupied homes were mortgaged, versus 67% on the mainland (U.S. Census). Residents in the large “unofficial” housing sector, which can include homes build on public land and subdivided family plots, may lack official title to their property, making a mortgage hard to obtain (Garcia 2021). Lack of title can also limit homeowners' access to any FEMA assistance that requires proof of ownership.[8]

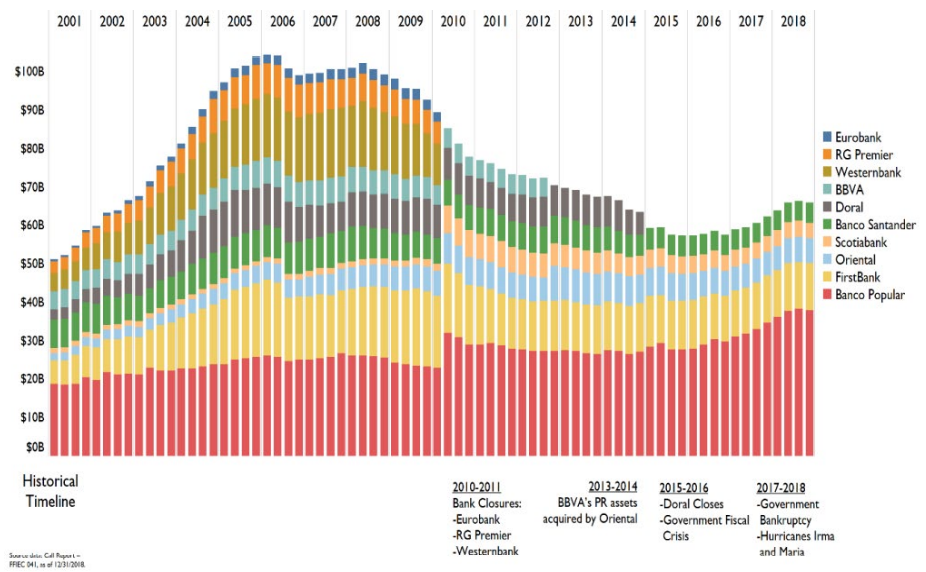
III.b Banking Conditions

The banking industry in Puerto Rico contracted along with its economy in the decade before Maria. Bank failures, consolidation, and firm exit shrank total assets held by commercial banks operating in Puerto Rico by over 40 % between 2006 and 2016 (**Figure 7**).

[7] In 2017, 68% of occupied homes in Puerto Rico were owner occupied, similar to the mainland rate of 64%. https://www.rand.org/pubs/research_reports/RR2595.html.

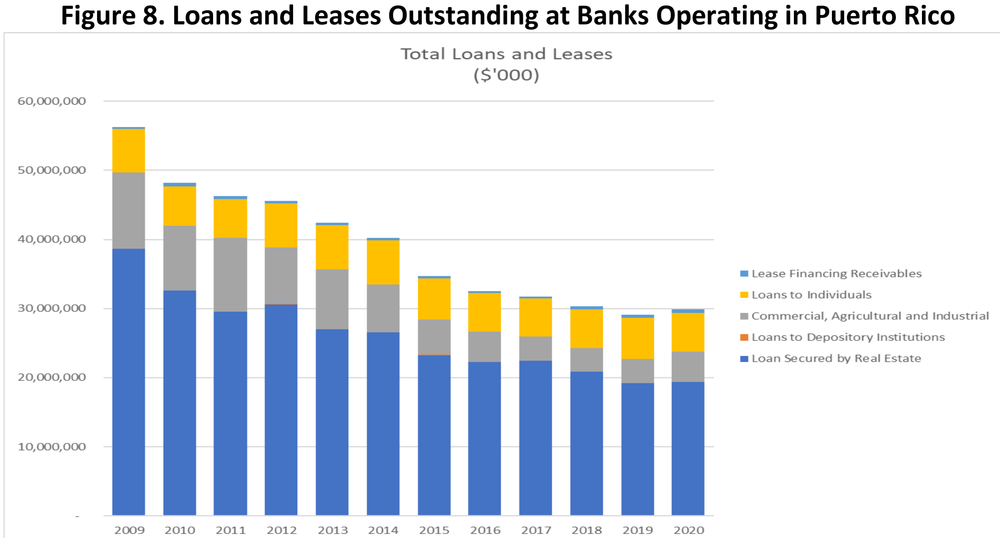
[8] The Jones Act (formally, the Merchant Marine Act of 1920), which prohibits foreign-flagged ships from transporting goods between U.S. ports, may have also hindered recovery although the Act was waived by the Trump Administration shortly after Maria struck.
https://www.nytimes.com/2017/09/28/us/jones-act-waived.html

Figure 7. Total Puerto Rico Commercial Banking Assets



Total loans outstanding by banks operating in Puerto Rico also contracted steadily in the years leading up to Maria (**Figure 8**). While demand from commercial borrowers remained weak, banks have experienced a resurgence in retail lending as demand for auto loans and other consumer unsecured loans have surged.

Figure 8. Loans and Leases Outstanding at Banks Operating in Puerto Rico



Source: Call Report FR-Y9C

III.c The Puerto Rico economy after Maria

The dual Irma/Maria hurricanes, occurring just weeks apart, exacerbated the already weak economic and financial conditions in Puerto Rico. Irma's rain and storm surge created an environment of an island that was already waterlogged and was not able to absorb even the early rains from Maria. Additionally, after Irma's initial devastation of certain Caribbean Islands, many neighboring islands, including Puerto Rico, sent people, aid, and supplies in response to Irma's destruction, not anticipating another storm of Maria's magnitude would arrive so shortly afterwards. This movement of critical resources away from Puerto Rico hindered the response to Maria.

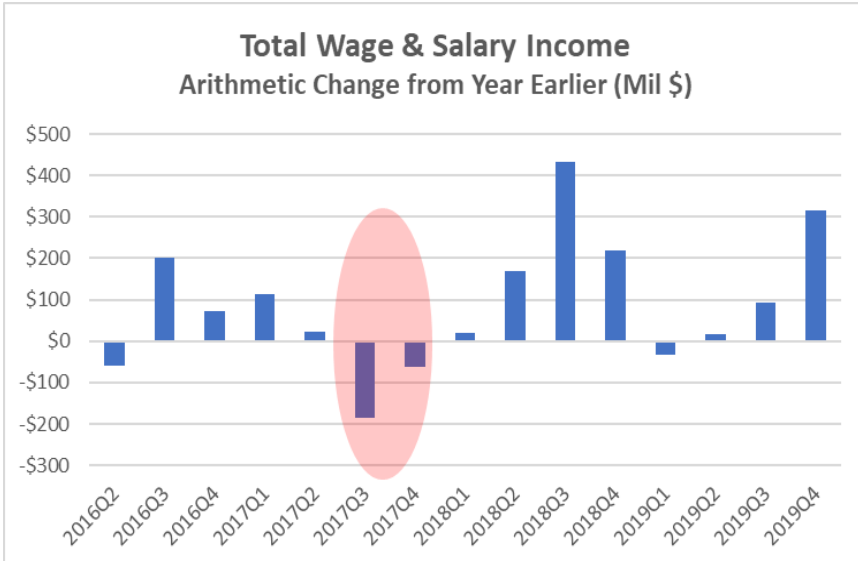
Widespread and protracted outages of power, communication, and water, as well as critical damage to bridges, roads, and other transportation links crippled Puerto Rico's economy in the Fall of 2017. From August to October 2017, private-sector employment fell by 7 percent (**Figure 9**). As it turned out, however, employment rebounded fairly quickly; by December 2017, nearly two-thirds of the initial job loss had been reversed, and by the following summer, employment was back up to pre-storm levels.

Figure 9. Employment in Puerto Rico Before and After Maria

Figure 10 shows that total wage and salary income dropped by about $250 million in the third and four quarter of 2017 but resumed growing by the first quarter of 2018.[9] Interestingly, growth later in 2018 was more robust than before Maria, consistent with Roth-Tran and Wilsons' (2022) finding that local economic growth tends to accelerate after disasters.

[9] Quarterly GDP growth are not available for Puerto Rico.

Figure 10. Wage and Salary Income in Puerto Rico Before and After Maria



Source: Bureau of Labor Statistics/Haver Analytics

IV. Bank Performance around Maria

IV.a Bank-Level Analysis

This section investigates how Puerto Rico banks fared, relative to a control group of banks, after Maria struck in September 2017. We focus on the three banks headquartered in Puerto Rico at the time - Banco Popular de Puerto Rico (BPPR), FirstBank and Oriental Bank. By 2017, these three banks controlled more than 75% of deposits on the island.[10] We find that delinquencies at these banks rose afterwards, but the effects were transitory. Charge-offs, capital, income, and lending were not affected while bank default risk fell slightly.

Data

Table 1 summarize the bank outcomes we study. The data are quarterly and come from bank holding companies' Y9-C reports.[11] The sample period is 2015q1 – 2019q3, a roughly 5-year span centered around 2017q3.[12] We converted all non-ratio variables to *log* terms to smooth out volatility for the Puerto Rico observations (of which there were, at most, 57). The control group comprises all U.S. banks that were not exposed to a natural disaster of any kind over between 2017q3 and 2019q3.[13] Consistent

[10] Cooperatives, akin to credit unions in the mainland U.S., comprised about 6% of on-Island financial sector assets at year-end 2020. Due to data limitations, we are not able to consider them in our analysis.
[11] We use Call Report data for Banco Popular PR to avoid confounding with Banco Popular NY.
[12] Extending the sample would add confounding effects from a merger later in 2019.
[13] More specifically, the control banks operated entirely in U.S. counties that did not have a FEMA-declared disaster between 2017q3-2019q3.

with the weak initial conditions just discussed, the Puerto Rico banks had (much) higher delinquency and charge off rates, lower Z-scores, and slower loan growth compared to the control group. On the other hand, they had higher income and capital/asset ratios.

Table 11. Descriptive Statistics for Puerto Rico Banks and Control Banks

	PR Banks			Control Banks		
	Mean	Median	N	Mean	Median	N
Log(Delinquency)	0.91	1.12	57	-2.10	-1.94	2,767
Log(Charge-offs)	0.26	-5.51	57	-8.33	-8.29	3,429
Log(Net Income)	17.21	17.20	52	12.48	12.54	4,916
Capital/Assets	13.17	13.40	38	11.72	10.98	5,108
Z-Score	54.05	39.32	57	168.61	151.13	5,055
Loan growth	-0.02	-0.01	57	0.01	0.01	5,107
Deposit growth	0.01	0.00	57	0.01	0.00	5,107

Source: Authors' calculation using data from Y9-C, Call Reports, and Census.
Note: All differences between means are significant at 1% level, except deposit growth. Sample period: 2015q1-2019q3. Control banks are those not facing any FEMA natural disasters between 2017q3-2019q3.

Analysis

This section applies difference-in-difference (DiD) analysis to assess the impact of Maria on Puerto Rico banks. To that end, we estimate regression models of the form:

$$P = \alpha + \alpha' x\, PR\_bank + \alpha'' x\, Post + \beta\, x\, PR\_bank\, x\, Post + controls + e.$$

The dependent variable, *P*, equals one of the performance measures above for each bank and date. The constant term, α, measures the mean of *P* over all sample. *PR_bank* equals one for Puerto Rico banks and zero for other banks. Its coefficient, α', measures the difference in the mean *P* for Puerto Rico banks versus control banks over the full sample period. *Post* equals zero before 2017Q3 and one on or after that date. Its coefficient equals the difference in mean *P* after Maria at all banks. The coefficient of interest, β, equals the relative change, or difference-in-difference, in *P* after Maria.

To control for other differences among banks, the regression model includes bank assets (lagged one quarter), population, median income, and the unemployment rate. The latter are measured at the Puerto Rico level for Puerto Rico banks and at the (weighted) county level for control banks. We also include a fixed effect (constant term) for each individual bank and date in the sample. Those control for differences across bank in their business models or operating markets that are constant over time as well changes in macroeconomic conditions that could affect performance.

Table 2 reports the results. For each outcome, the first number reported is the DiD (β) estimate and the second is the standard error. We see in Column 1 that delinquency rates at Puerto Rico banks rose significantly relative to the control, after Maria. The increase of 1.003 implies Puerto Rico delinquency rates roughly doubled post-hurricane relative to control banks. Charge-offs rates, by contrast, did not rise significantly.

We also observe higher Z-scores (lower default risk) post-hurricane. The effect is large, but only marginally significant at the ten percent level. Apart from the effects on delinquencies and Z-scores, we observe no significant change in any outcome. In particular, loan growth does not change significantly.

Table 2. Relative Impact of Hurricane Maria on Puerto Rico Banks

	Log(Delinquency)	Log(Charge-Offs)	Log(Net Income)	Capital/Assets	Z-Score	Loan Growth	Deposits Growth
	1.003**	0.118	0.0481	-0.291	30.42*	-0.004	0.004
	-0.461	-0.217	-0.078	-1.254	-15.266	-0.007	-0.003
Observations	2807	3480	4967	5145	5112	5164	5164
R^2	0.498	0.657	0.879	0.944	0.823	0.175	0.118

Note: Reported are DiD regression estimates. Robust standard errors, clustered by state, reported in parenthesis. Regression models include income, unemployment, population, bank assets (lagged one quarter), and bank and date fixed effects. Sample period: 2015q1-2019q3. Control banks are those not facing any FEMA natural disasters between 2017q3-2019q3.

Table 3 shows how the impact of the hurricanes on delinquency rates by individual loan category. Many banks did not report these data, so the number of observations (and power of the statistical tests) is lower accordingly. That said, we see that delinquency rates on all categories tended upward after the hurricane, although only increase in residential mortgage delinquencies is statistically significant. That finding for mortgages is notable given the preponderance of those credits on PR banks' balance sheets noted earlier.

Table 3. Impact of Maria on Log(delinquency) Rates by Loan Category

	(1) Residential Mortgage	(2) Commercial Real Estate	(3) C+I	(4) Consumer	(5) Other Loans
DiD	0.686**	0.627	0.239	0.202	0.000
	(0.280)	(0.688)	(0.362)	(0.266)	(.)
Observations	1381	580	845	1768	616
R^2	0.509	0.523	0.526	0.565	0.676

Standard errors in parentheses

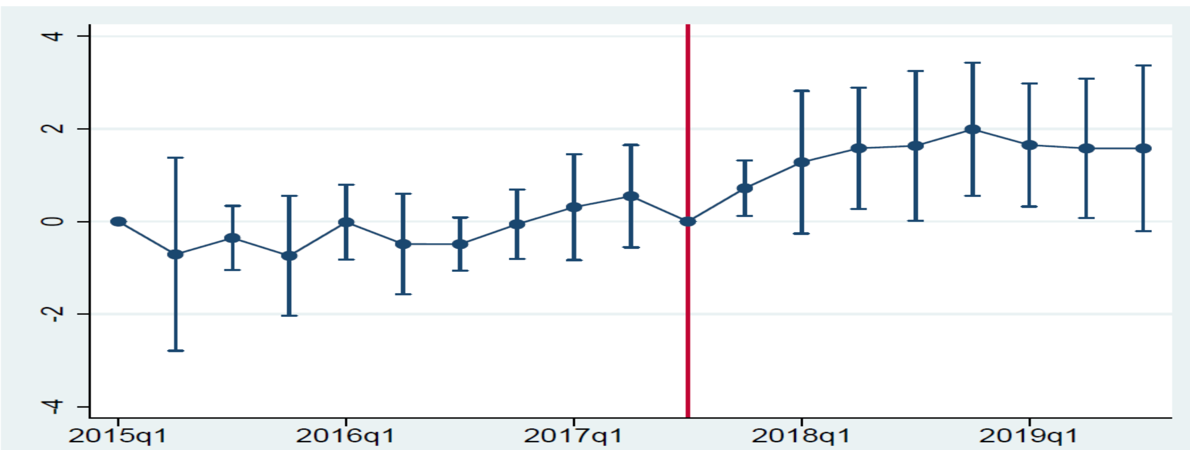
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Reported are DiD regression estimates. Robust standard errors, clustered by state, reported in parenthesis. Regression models include income, unemployment, population, bank assets (lagged one quarter), and bank and date fixed effects. Sample period: 2015q1-2019q3. Control banks are those not facing any FEMA natural disasters between 2017q3-2019q3.

Parallel Trends?

The maintained assumption in our DiD analysis is that the trends in outcomes for the Puerto Rico banks and the control banks were parallel before Maria. Granting that, any difference afterwards can plausibly be attributed to Maria. To check the parallel trends assumption, in **Figure 11** we plot dynamic DiD estimates for delinquency rates. The dot at each date equals the difference between mean delinquencies at Puerto Rico banks and control banks relative to their difference at 2017q3. The "wings" through the dots are confidence bands; if they bisect the zero axis, the difference is not significantly different from zero with 95 percent confidence. We see that the difference between delinquencies at Puerto Rico and control banks before Maria was essentially constant, that is, delinquency rates at Puerto Rico banks were higher, as noted above, but the *difference* was not trending upward (or downward) before 2017q3. Delinquency rates at Puerto Rico banks rose relatively only *after* the hurricane, consistent with the DiD estimates above. The new insight here is that the rise in delinquencies was transitory; it peaked in 2018q4 and by 2019q4 the difference between Puerto Rico banks and the control was insignifcant (at the 95 percent confidence level).

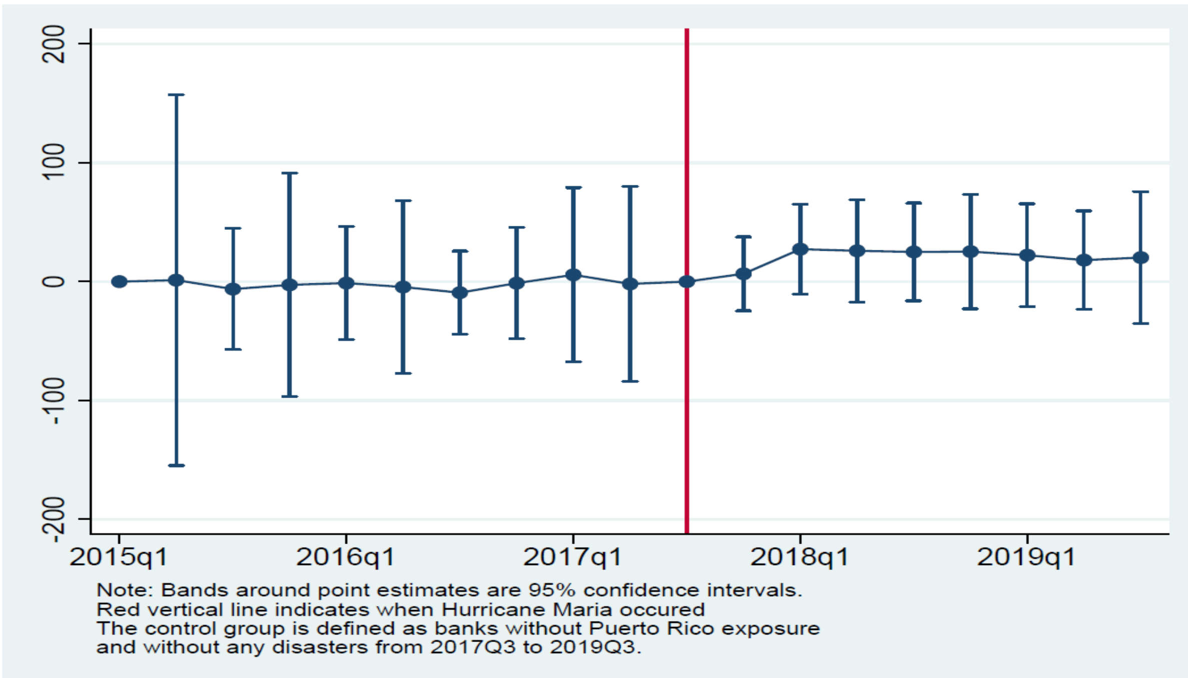
Figure 11. Difference Between *Log*(delinquency) Rates at Puerto Rico Banks and Control



Note: Bands around point estimates are 95% confidence intervals.
Red vertical line indicates when Hurricane Maria occured
The control group is defined as banks without Puerto Rico exposure
and without any disasters from 2017Q3 to 2019Q3.

Figure 12 shows the dynamic DiD for Z-scores, or distance-to-default. No pre-hurricane differences are apparent. Afterwards, Z-scores for the Puerto Rico banks edged upward (relatively) but no differences at given date are significant at the 95 percent level. The cumulative differences over the post-hurricane period are significant, however, at the 90 percent level, as reflected in the main results above.

Figure 12. Difference Between Z-score at Puerto Rico Banks and Control



Discussion

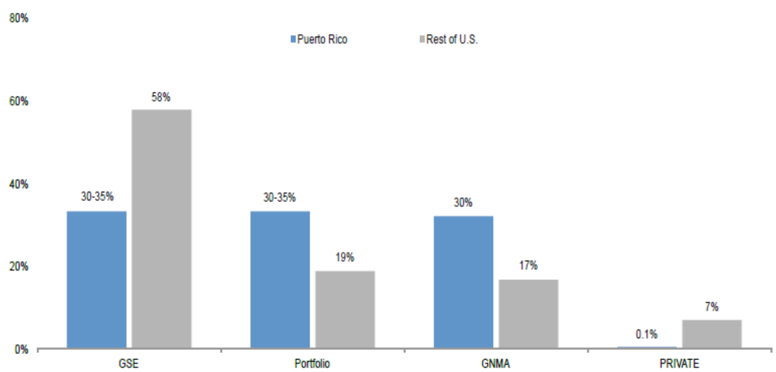
Though perhaps surprising, the relatively modest, transitory impact of Hurricanes Irma and Maria on Puerto Rico banks is consistent with other recent studies. Brei et al. (2016) find that Caribbean banks experience tighter liquidity conditions after hurricanes, but not increased loan defaults or weakened capital. Gallagher and Hartley (2017) find the household delinquency rates spike after Hurricane Katrina, but the impacts were "modest in size and short-lived." Studying extreme weather of all types, Blickle et al. (2022) also finds modest, short-term effects on bank loss rates.

IV.b Mortgage performance

This section delves deeper into how residential mortgages performed after Maria using granular data from the McDash Residential Mortgage Servicing Database ("McDash"). These data give a broader view of mortgage performance after Maria as they include not just mortgages held in bank portfolios, as studied above, but also mortgages owned by owned or guaranteed by federal government sponsored enterprises (GSE) and other U.S. housing agencies. With the additional detail we can compare mortgage performance by ownership or insured status.

As of October 2017, McDash reported approximately 425,000 mortgages on homes in Puerto Rico. For comparison, that is roughly the same number of active mortgages on Iowa residences. **Figure 13** compares the ownership of Puerto Rico mortgages, whether held in banks' portfolios, or securitized in October 2017. Between 30-35 percent of Puerto Rico mortgages are held in portfolio by banks, versus just 19% for the mainland.[14] A correspondingly smaller share were securitized and backed by either the GSEs (government sponsored enterprises – Fannie Mae and Freddie Mac) or the GNMA (Government National Mortgage Association - Ginnie Mae): 60-70% for Puerto Rico versus 75% for the mainland share was notably higher for Puerto Rico mortgages. Private label securitization (PLS) was also much lower in Puerto Rico, relatively non-existent in fact. The reasons for the lower securitization rates are unclear though it may have to do with the property title issues discussed earlier.[15]

Figure 13. Mortgage Ownership in Puerto Rico and Mainland U.S. in October 2017



Source: Black Knight Mortgage Monitor, October 2017.

Figure 14 shows the impact of Maria on mortgage delinquencies using data from the Puerto Rico government (red line)[16] and the McDash database (blue line). At the time Maria struck, more than 10% of the active mortgages on the island were already delinquent. The rate roughly tripled by November but had returned to pre-Maria levels one year later. In the appendix we show how loan performance paralleled Maria's path across the island.

The sharper rise here compared to that observed using bank regulatory data in the previous section could reflect differences in the quality of mortgages held by banks and those that have been securitized. Another factor could be the foreclosure moratoriums enacted after Maria could be another factor. The moratorium, declared by various government housing authorities (HUD, FHA, Fannie Mae, Freddie Mac, and USDA) was in place between 2017q4 and 2018q3. That would tend to suppress delinquencies reported by banks (or credit bureaus) but not McDash, which bases delinquencies on actual payments by borrowers to lenders and not delinquencies reported by lenders to credit bureaus or regulators.

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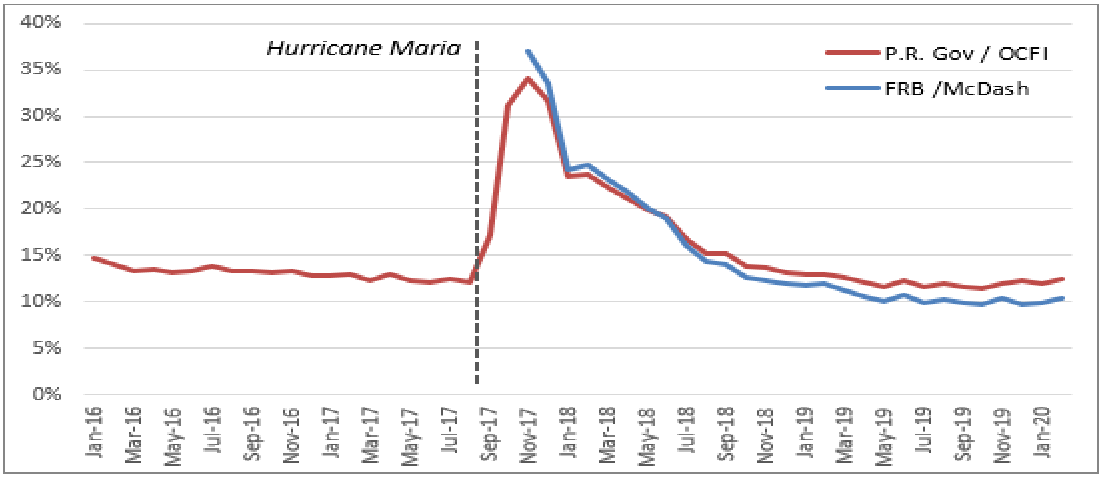
[14] Based on HMDA reporting, Puerto Rico headquartered banks hold 50% of island mortgages with the balance held by banks headquartered in the mainland US, foreign banks, independent mortgage banks and cooperativas.

[15] For FEMA's hurricane damage, see OpenFEMA Data Sets | FEMA.gov; Fischbach et al.: "After Hurricane Maria: Predisaster Conditions, Hurricane Damage, and Recovery Needs in Puerto Rico." and The Housing Crisis in Puerto Rico and the Impact of Hurricane Maria | Centro de Estudios Puertorriqueños.

[16] Office of the Commissioner of Financial Institutions (OCFI), Puerto Rico Financial Activity Report December 2020

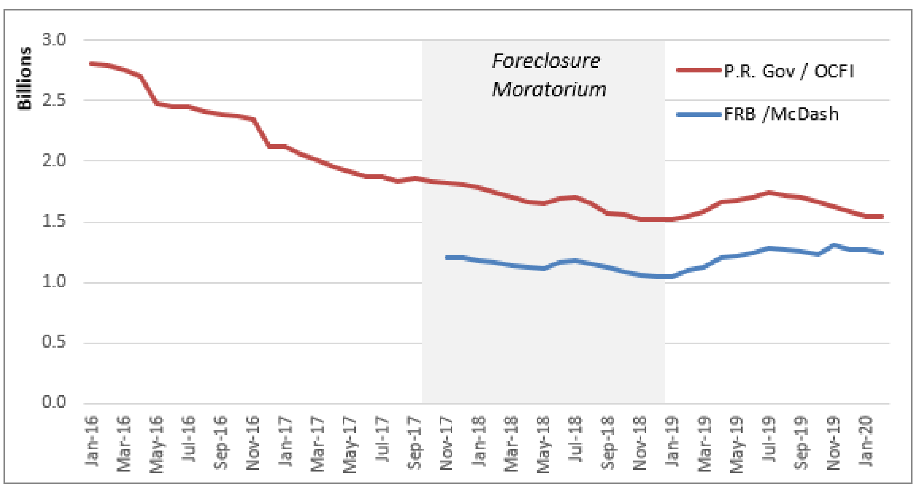
Figure 14. Mortgage Delinquency Rates in Puerto Rico



Source: McDash and Office of the Commissioner of Financial Institutions (OCFI) Puerto Rico Financial Activity Report (December 2020)

Figure 15 shows trends in foreclosure after Maria. Despite the sharp spike in delinquencies just noted, foreclosures continued downward during the moratorium. After the moratorium was lifted, foreclosures rose for several months before returning to trend after about a year. Many of the mortgages foreclosed on in 2019 were likely delinquent before the Maria, so the impact of Maria appears modest.

Figure 15. Properties in Process of Foreclosure

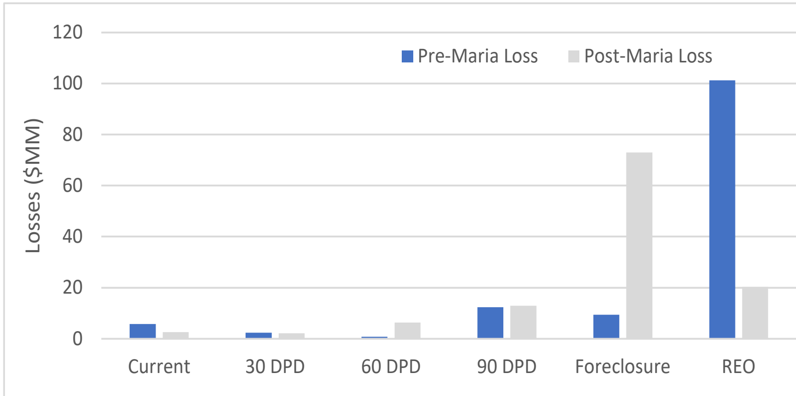


Source: McDash and OCFI Puerto Rico Financial Activity Report (December 2020)

Figure 16 compares mortgage loan losses before and after Maria for all Puerto Rico portfolio loans in the McDash dataset as of November 2017 (the first month for which sufficient data is available).[17]

[17] Note that loss information is not provided for GSE loans in McDash.

Figure 16. Portfolio Loan Losses by Delinquency Status in November 2017



Source: McDash

Note: Pre-Maria is January 2016- August 2017. Post-Maria is September 17 to December 2019.
REO is real estate owned by lenders due to foreclosure.

The vast majority of incremental losses after Maria were on loans that were already at least 90 DPD before the hurricanes hit the island. However, it is also possible that the impact of the hurricane exacerbated losses in these already troubled loans. Even before the storm, Puerto Rico was mired in a severe housing slump. Home prices over the preceding decade had fallen by 25 percent, and lenders had foreclosed or filed to foreclose on 60,000 home loans, according to the Puerto Rico state court system.

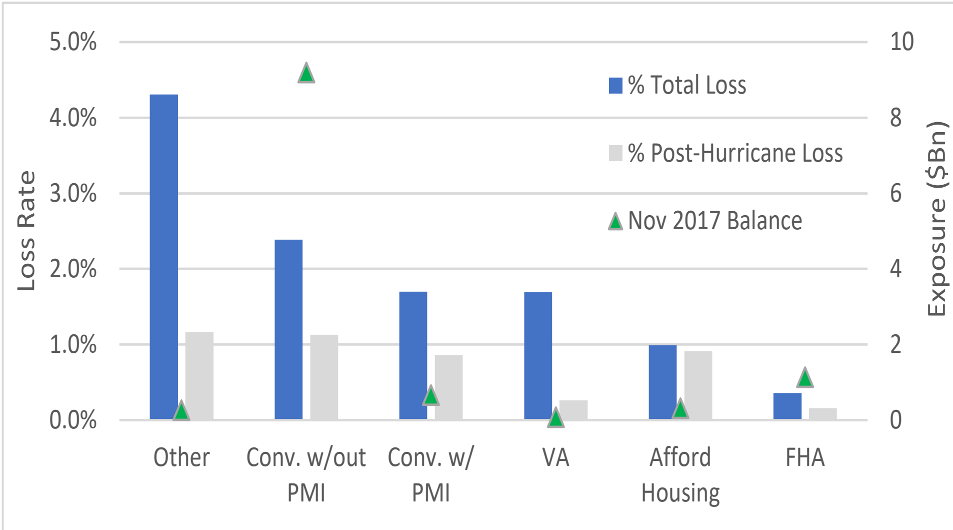
Figure 17 shows loss rates for mortgages held by banks in November 2017.[18] "Total losses" are through December 2019 (15 months after the moratorium ended) while "post-Hurricane losses" are losses after November 2017. Loss rates are notably higher for conventional ("conv") loans without private mortgage insurance[19] including FHA-backed loans.[20] 37% of all loans in the McDash database as of November 2017 are federally backed (VA, FHA) or conventional with private mortgage insurance (PMI) which would have served to limit credit losses to banks or (non-guarantor) investors holding them. Furthermore, Fannie Mae, Ginnie Mae, and FHLMC owned 65% of balances and only 34% were owned by banks and credit unions. In the appendix we show how mortgage delinquencies and losses varied across the island.

[18] Loss data in McDash is only available for Portfolio loans, which are a subset of total mortgage loans ($11.7BN of $30BN mortgage principal balance in November 2017).

[19] Private Mortgage Insurance (PMI) is mortgage insurance that it is typically paid by the borrower for the benefit of the mortgage lender in the event of borrower default. A default by the borrower results in the lender being reimbursed for the associated loss, with no benefit to the borrower. The GSEs require borrowers to take out PMI for loans with initial down-payment LTV over 80%.

[20] Loans backed by the FHA (Federal Housing Authority) are intended as affordable loans with low down-payments for first time and less well-to-do borrowers. These loans require borrowers to pay to the FHA an upfront as well as annuitized insurance premiums in addition to loan interest and principal. FHA loans tend to be popular in Puerto Rico where loan sizes are typically smaller and income levels lower than in the continental US. VA loans are intended for veterans and also focused on affordable with no mortgage insurance requirements.

Figure 17. Loss Rates on Bank-Held Mortgages, by Type



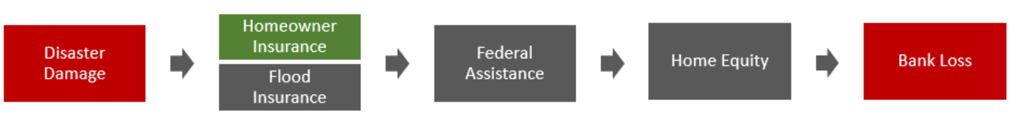
Source: McDash

V. Why Were Bank Losses So Low?

Given the destruction and disruptions caused by Maria and the weak initial conditions, it may be surprising that the impact on banks was not worse that it was. This section discussion various protections that may have limited the impact to banks that were lending in Puerto Rico at the time of the 2017 hurricane season.

Figure 18 illustrates the layers of protection that potentially mitigate losses to mortgage holders, starting on the left with the gross damages, working through the various layers of financial protection – homeowners and flood insurance, federal assistance, homeowners' equity, and finally to the potential for bank loss. We discuss these in turn.

Figure 18. Mortgagee Protection from Disaster Damages



Source: An, Binder, Biswas, Dice, and Houssain (2021)

Homeowners' Insurance

The home is the asset securing the mortgage, so homeowners insurance provides a valuable layer of protection to banks from disaster damages. In Puerto Rico, however, homeowner insurance coverage as relatively low. As reported in Ma, Smith, and Baker (2021), a sample of 265,807 owner-occupied homes that experienced damage from Hurricanes Irma and Maria revealed that only about 20% had homeowners' insurance. Moreover, they find that coverage was inversely related the level of damage from Maria.[21] However, mortgage lenders have a strong incentive to ensure that mortgage borrowers maintain homeowners' insurance to protect the value of the collateral in case of natural disasters such as hurricanes.

Flood Insurance

Flood damage is not typically covered by homeowners' insurance policies and so requires a separate policy. In Puerto Rico, less than 4% of households have flood coverage. Of homes that suffered roof damage, only 11% had homeowners' insurance. Low homeowner insurance coverage reflects both the low average income in Puerto Rico and the high cost of insurance in an area where floods and other weather disasters are endemic. Additionally, many resident with homeowners' insurance were unaware of the extent of their coverage, with many filing insurance claims for damage from Maria was not, in fact, covered by their insurance policies.[22] Many also purchased policies from small, private insurance companies that were underregulated and underfunded, some of which (e.g., Real Legacy and Integrand) failed after Maria without fulfilling their obligations.

The U.S. banking laws requires flood insurance on homes located in the 1% annual risk floodplain ("100-year floodplain") with a mortgage issued from a federally backed lender. However, there are no requirements for purchase of insurance outside of the 1% annual risk floodplain or from other hazards, such as wind or landslides, which contributed to losses after Maria.

FEMA disaster assistance

After a natural disaster such as a hurricane occurs, FEMA provides aid through its Public Assistance (PA), Individual Assistance (IA), and Hazard Mitigation Grants (HMGP) programs. The scarcity of flood insurance in Puerto Rico made its residents heavily reliant on FEMA's disaster assistance. Despite sometimes lengthy delays in awarding aid, within nine months after Maria, FEMA had approved $1.2 billion in individual assistance (to 452,386 applicants), $19.3 billion in public assistance, and $54 million in hazard mitigation assistance (Hinojosa and Meléndez, 2018). Because the vast majority of the aid went to public agencies rather than residents, it would seem to provide little direct protection to banks. Moreover, FEMA Individual Assistance is only intended to make homes safe and habitable, not restore them to pre-storm conditions. Thus, the property could still be depreciated relative to any mortgage obligation.[23]

Mortgage Insurance

Mortgage insurance guarantees mortgage lenders against default by homeowners. Although homeowners benefit from improved credit access, payments from the mortgage insurance goes to the mortgage issuing institution and not to the homeowner. The U.S. has both private mortgage insurance ("PMI") and public (government) mortgage insurance.

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[21] Three levels of severity (Minor Damage, Major Damage, and Destroyed) were assigned to homes damaged from the storms. Of homes that suffered a minor level of damage, 20% were covered by a homeowners insurance policy, while homes that had a major level of damage or were destroyed had a 5% and 1% coverage rate respectively.

[22] This lack of awareness appears to be prevalent. Fannie Mae Survey Underscores Opportunity to Raise Consumer Awareness About Flood Risk and Flood Insurance | Fannie Mae

[23] Blickle et al (2021) find no evidence that FEMA aid mitigates disaster effects on banks.

Frequently, banks require PMI for borrowers who have low credit scores or low down payments (frequently under 20% of the mortgage borrowed). PMI pays off regardless of why default occurred – whether due to storm damage or because the homeowner can no longer afford their mortgage. As demonstrated in Section IV's Figure 17 above, mortgages with PMI suffered smaller losses than mortgages without PMI post-Maria, suggesting PMI acted as a financial loss mitigant for lending institutions.

Several U.S. agencies also provide mortgage insurance. The Federal Housing Administration (FHA) guarantees mortgages taken out by eligible low-income households. The homeowner generally has a low credit score and/or can afford a small down payment (as little as 3.5% of the mortgage).[24] The Veterans Administration (VA) has a similar program to support homeownership of veterans of the armed forces. As demonstrated in Section IV's Figure 17 above, FHA and VA mortgage insurance helped protect banks in Puerto Rico from financial losses from Maria, with post-hurricane loss rates much lower for FHA and VA loans than for loans with or without PMI.

GNMA and the GSEs sell mortgage insurance to banks. These GSEs do not offer mortgages directly to homeowners, but some homeowners benefit indirectly, as banks are more likely to issue home mortgages knowing that there is the ability to purchase mortgage insurance from these agencies. Additionally, GSE mortgage insurance may be attractive to banks, given the conclusion of Gete and Tsouderou (2022) that GSE do not fully account for the risks of natural disasters when they price mortgage insurance.

VI. Discussion and Conclusions

This study analyzed bank financial performance in the face of hurricanes Irma and Maria in 2017. Maria was, in many ways, a worst-case scenario – by most measures, it was the worst hurricane to hit Puerto Rico since 1928 and it struck just two weeks after Irma saturated the island. Moreover, the island was vulnerable to begin with after a decade of economic decline and a shrinking banking sector. Despite all that, we find Maria had only a modest, short-term impact on banks' performance and no negative effects on their lending.

We discussed various financial protections, including homeowners' insurance in the case of residential real estate lending, government emergency assistance, and publicly arranged mortgage insurance (e.g., FHA, VA, and GSE), that helped safeguard banks' lending portfolio and ensure relatively mild and short-lived financial impacts.

A deeper dive into mortgage portfolio performance identified federal mortgage insurance (FHA, VA, and GSE) as an important risk mitigant to losses to the mortgage-issuing banks in Puerto Rico. These government-organized mortgage insurers were intended to charge fair prices for their guarantees provided, but, in practice, direct and cross-subsidies have occurred in these markets. The FHA, for example, has not maintained sufficient fees and premiums to pay off their defaulted mortgages and has required sizable transfers from US Treasury as direct subsidy. As a cross-subsidy within the GSEs, Gete and Tsouderou (2022) demonstrate that the GSEs tend to mis-price mortgage insurance by

[24] In exchange, the homeowner must pay a one-time fee at origination and a monthly insurance premium for the life of the mortgage.

undercharging properties at greater risk for hurricane damages and overcharging properties at lower risk.

One important idea coming out of this analysis relates to the value of current, reliable information in ensuring efficient allocation and proper pricing of risk. Delays in updates of FEMA flood charts results in unintended risk-taking by those who unknowingly rely on outdated charts. Additionally, FEMA's delay in updating their flood models in Puerto Rico resulted in their overcharging for flood insurance in certain instances, which encouraged private insurance companies to enter the market, some of which defaulted on their obligations after Maria. Furthermore, the GSEs have not properly priced hurricane risk for their mortgage insurance, thus effectively subsidizing mortgages in hurricane-prone areas.

During recent decades, as the size of catastrophic events and their related economic losses have been rising, the amount of government subsidization has been on the rise. For example, funding for FEMA's national flood insurance program (NFIP) comes primarily from policy premiums and fees (augmented by annual appropriations for certain administrative activities such as flood mapping) and is supposed to be sufficient to pay off participant claims. However, a series of large losses to NFIP, beginning with Hurricane Katrina in 2005 and continuing with Hurricanes Ike, Sandy, and Harvey, forced Congress to pay down NFIP's accumulated debts of $16 billion in 2016, yet NFIP still had over $20 billion in debt just four years later (Linder-Baptie, Epstein, and Kousky, 2022). These large and growing subsidies from the Federal government raises questions about the sustainability of these programs and their protection to banks' mortgage portfolios as the climate change continues.

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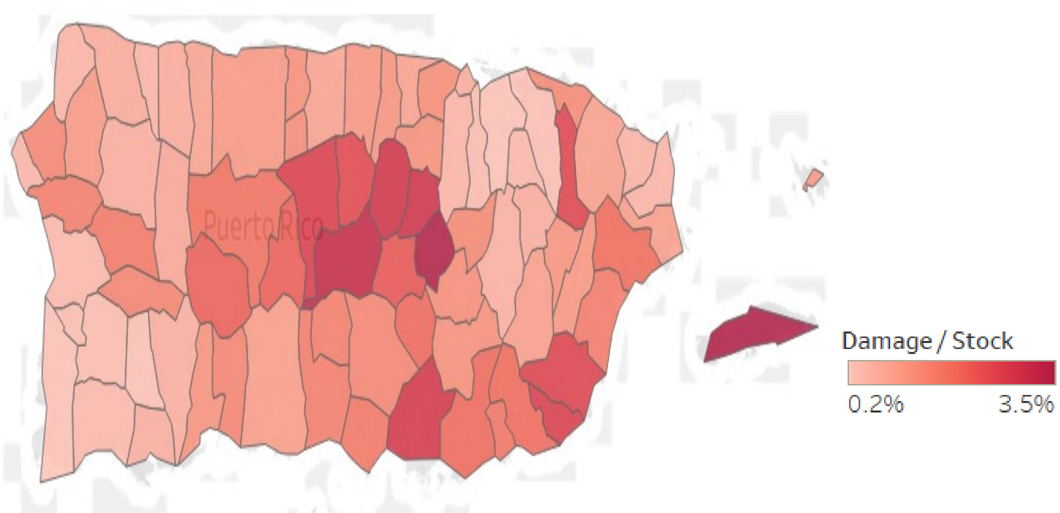
APPENDIX

Figures A1 – A3 below highlight the geographical pattern of delinquencies and hurricane damage across the 78 municipalities of Puerto Rico.

- **Figure A1** shows the total amount of residential hurricane damage estimated by FEMA normalized by the estimated total housing stock for each municipality. [25] This damage rate roughly corresponds to the path of the hurricane across the island, from the southeast to the northwest.
- **Figure A2** shows the initial rise (two months after the event) in the non-current mortgage rate, are including loans in foreclosure and REO. The greatest delinquency effects are in the central and southeastern portions of the island, a pattern consistent with Maria's path. The more heavily populated northeastern region experienced slightly lower delinquency rate increases.[26]
- **Figure A3** shows the serious delinquency rate (90 days + DPD) as of Dec 2018, or 14 months after the Maria. Of the island's 78 municipalities, all are reporting at least some degree of lingering impact, with 33 having 100 or more serious delinquencies remaining. The more heavily populated areas of the northeast saw the largest volumes of serious delinquencies.

Figure A1: Total FEMA Damage / Housing Stock by Municipality

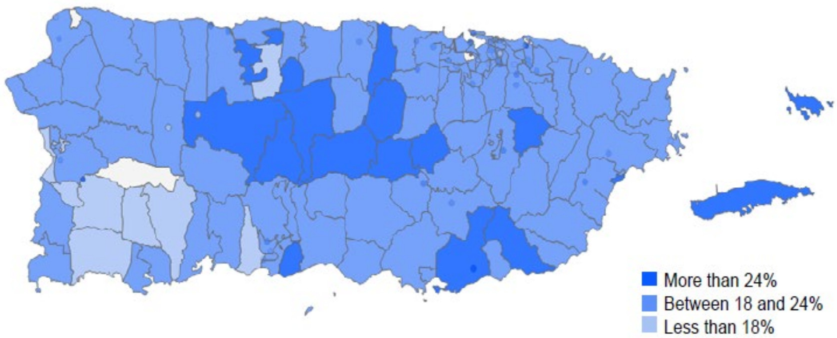


Source: McDash

[25]Damage estimates are from [OpenFEMA Dataset: Housing Assistance Program Data - Owners - v2](https://www.fema.gov/)
Housing stock estimates are from the City University of New York, "The Housing Crisis in Puerto Rico and the Impact of Hurricane Maria – June 2018."
https://centropr-archive.hunter.cuny.edu/sites/default/files/data_briefs/HousingPuertoRico.pdf

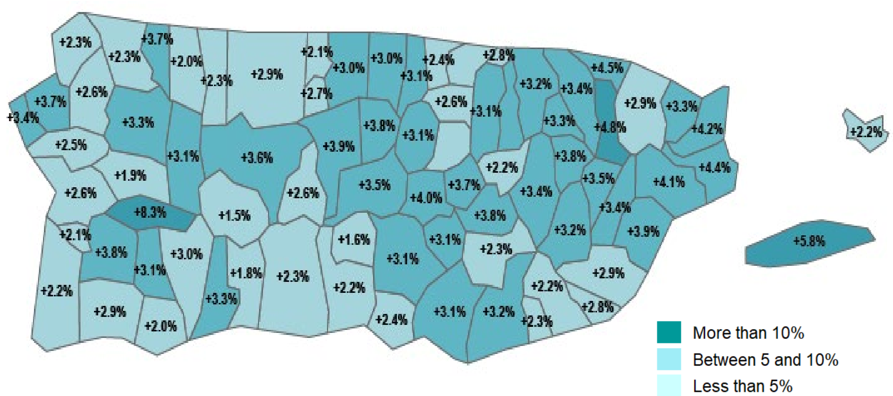
[26] Black Knight October 2017 MortgageMonitor Report

Figure A2: Two-Month Rise in Non-current Rate for Home Mortgages (Sep - Oct 2017)



Source: Black Knight October 2017 Mortgage Monitor

Figure A3: Share of Seriously Delinquent Mortgages as of Dec. 2018



Source: Black Knight January 2019 Mortgage Monitor

There is a moderate, positive correlation between municipality-level hurricane damage and delinquency rates as of December 2017 and December 2018 (32% and 22% correlation respectively). However, the widespread macroeconomic impacts of the hurricane may have had an even greater impact on loan performance than the physical damages. For example, we found a moderate negative correlation (-0.27) between the change in employment post Maria and hurricane damage rates at the municipality level. Delinquency rates tended to be significantly higher for portfolio loans than for GSE loans. This may reflect differing underwriting standards (average origination FICO is lowest for portfolio loans) as well as servicing practices.