There Is No Post Hurricane World

Data Mining to Uncover Persistent Effects of Natural Disasters

Alexander Gonzalez-Torres
College of Engineering
and Applied Science
University of Colorado
Boulder, Colorado
algo9142@colorado.edu

ABSTRACT

We sought to determine whether natural disasters permanently changed the socioeconomic trajectory of countries by data mining the World Development Indicators and the Emergency Disaster Database. Exploratory Data Analysis suggested that this is not necessarily the case. We found only one country where a natural disaster changed its socioeconomic trajectory: Puerto Rico after Hurricane Maria in 2017. After this discovery, we focused on Puerto Rico and tasked ourselves with finding which areas of social and economic development were permanently affected by Hurricane Maria in the American territory. We designed a data pipeline to systematically mine our database and uncover Development Indicators that were permanently affected by Maria. We found that Maria negatively and permanently affected the following areas of socioeconomic development in the Commonwealth:

1. Food Production and Nutrition
2. Public Sentiment
3. Energy
4. Education
5. Economic Productivity

These findings suggest that—indeed—there is no post hurricane world in Puerto Rico. The Commonwealth struggles to recover across key areas of social and economic development, 7 years after Maria. While these findings point towards a somber future for the American territory, they also offer local and federal leaders actionable areas in which to focus recovery efforts.

CCS CONCEPT

Applied computing →
Law, social and behavioral sciences →
Economics

KEYWORDS

Hurricane Maria, Commonwealth of Puerto Rico, World Development Indicators (WDI), Emergency Events Database (EM-DAT), natural disaster, time-series analysis, data pipeline.

BACKGROUND

Hurricane Maria ("Maria") made landfall in the American territory of Puerto Rico on September 16, 2017. The Category 4 cyclone caused a systemwide collapse of Puerto Rico's energy system. The largest blackout in United States history, and second largest in the world, followed [1].

Homes away from the San Juan metropolitan area would not regain power for 10 months following Maria. The childhood home of Alexander Gonzalez-Torres would not regain power until July 2018.

A May 2018 study by the Harvard T.H. Chan School of Public Health estimates that up to 4645 people perished in Maria's wake. The initial

death count by the Government of Puerto Rico was 64. Local authorities updated the official figure to 2975 following international scrutiny [2].

These conditions exacerbated civil discontent in the beleaguered Commonwealth, which marked 10 years of economic recession in 2017 [3].

In July 2019, local media published screenshots of a Telegram group chat between Governor Ricardo Rosselló, members of his Cabinet, and political operatives. In the group chat, Governor

Rosselló and allies made remarks such as "great job guys, we fool even our own people" and "I saw the future and it was beautiful, there are no more Puerto Ricans" [4].

In July 2019 as well, federal prosecutors charged six officials of the Rosselló administration with various corruption charges. Rosselló's first Secretary of Education, Julia Keleher, was among the accused [5].

Civil unrest followed 'TelegramGate' and the arrests. After weeks of mass demonstrations, in August 2019 Ricardo Rosselló became the first democratically elected Governor of Puerto Rico to resign. Protestors cited the death toll of Maria and the Rosselló Administration's management of disaster relief as reasons for their discontent [6].

Anecdotally, Puerto Rico changed after Maria. In November 2022, the Whitney Museum of American Art inaugurated "*No existe un mundo poshuracán*: Puerto Rican Art in the Wake of Hurricane Maria." The title translates to *There Is No Post Hurricane World*. Marcela Guerrero, the exhibition's lead curator, states that *There Is No Post Hurricane World* "contends with the fact that the true disaster is perpetuity… the sensation that Puerto Ricans are trapped, and will continue to be trapped, in the wakes of Maria." She adds that Puerto Rico after Maria "is an omen of what can happen to the vulnerable, not only in the Caribbean but in the World" [7].

INTRODUCTION

Extrapolating from Guerrero's statements, we initially sought to answer the following questions:

1. Is Puerto Rico truly trapped in the wake of Hurricane Maria?
2. Are other countries trapped in the wake of severe natural disasters?
3. What conditions produce the persistent effects of natural disasters?
4. What methods can we use to study the persistent effect of natural disasters?

The answer to these questions could provide world leaders with novel insight on preventing and mitigating the persistent effects of natural disasters. Furthermore, it builds on emerging research within the field of disaster studies by emulating and verifying data mining methods and insights derived from our data set.

We began research by quickly evaluating socioeconomic data published in the World Bank Group's *World Development Indicators* ("WDI") [8] in conjunction with data extracted from the Center for Research on the Epidemiology of Disasters's *Emergency Events Database* ("EM-DAT") [9]. First, we selected 100 randomized social and economic Development Indicators ("Indicators") in 4 countries: the Philippines, Puerto Rico, Japan, and the United States of America. These countries exist in distinct regions, income levels, growth levels, and quality of infrastructure. They were selected to control for these factors.

We then conducted a time-series analysis between 1960 and 2023 for these Indicators by plotting the data and marking years with natural disasters in the selected countries. We hoped to find that Indicators in the selected countries changed their trend after severe natural disasters,

like a cyclone with high sustained wind speeds or an earthquake of high magnitude.

We did not find this during Exploratory Data Analysis ("EDA"). For the majority of selected Indicators, we could not find a change in trend following a severe natural disaster. For the Indicators where we found such a change, the trend reverted to pre-disaster levels within 3 years in most selected Indicators. Puerto Rico was the exception.

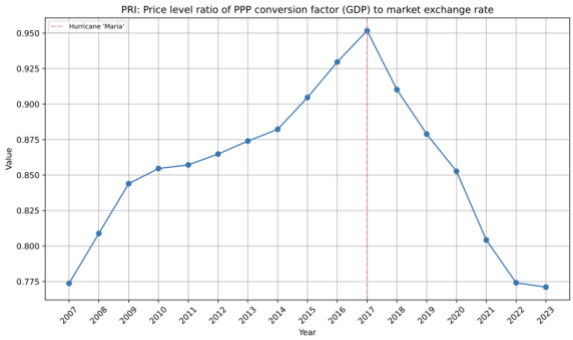


Figure 1. Puerto Rico: Price level ratio of PPP conversion factor (GDP) to market exchange rate (2007-2023).

Some Indicators selected for Puerto Rico showed dramatic trend reversals following Maria. For example, the Indicator in Figure 1 measures the relative cost in goods and services between a given country and the United States. This figure suggests that Maria reversed a trend towards price parity between Puerto Rico and the mainland by exerting deflationary pressure that persists into 2023.

Following EDA, we knew the following about our initial questions:

1. Maria's effects on Puerto Rico's social and economic wellbeing seem to persist today.
2. This relationship between severe natural disasters and WDI's Indicators does not necessarily repeat in other countries.
3. Given that this relationship did not repeat in other countries, we cannot hypothesize about what conditions lead to persistent socioeconomic effects following a severe natural disaster.
4. We can use data extracted from WDI and EM-DAT to study the persistent effects of natural disasters, particularly in Puerto Rico.

Consequently, we decided to narrow our scope and focus on Puerto Rico in the wake of Maria and sought to answer the following question:

1. Which areas of social and economic development were permanently affected by Hurricane Maria?

For purposes of this paper, we consider an Indicator "permanently affected" if:

1. Maria meaningfully changed its trend.
2. This change in trend has not reversed by 2023.

We proceeded by developing a data pipeline ("Pipeline") in Python that can extract data for any country from WDI and EM-DAT. This data is then transformed and loaded into DataFrames for analysis. Finally, the Pipeline conducts time-series analysis and produces a report with plots for visual analysis. The analysis step of the Pipeline marks years in which a meaningful natural disaster occurred.

As the Pipeline is modular, it can extract data for any time period between 1960 and 2023. We used 2007-2023 as our time period to account for global events that could affect the Indicators such as the 2008 Recession and the COVID-19 Pandemic.

After running the Pipeline using Puerto Rico's WDI and EM-DAT data between 2007 and 2023, we conclude that Maria negatively and permanently affected the following areas of socioeconomic development in the Commonwealth:

1. Food Production and Nutrition
2. Public Sentiment
3. Energy
4. Education
5. Economic Productivity

These findings suggest that—indeed—there is no post hurricane world in Puerto Rico. The Commonwealth struggles to recover across key areas of social and economic development, 7 years after Maria. While these findings point towards a somber future for the American territory, they also offer local and federal leaders actionable areas in which to focus recovery efforts.

RELATED WORK

A review of available literature confirms that we can use data extracted from WDI and EM-DAT to accurately study the persistent effects of natural disasters. Disaster researchers use the World Development Indicators to uncover persistent effects of natural disasters. For example, Noy (2009) used WDI to find that economic output declines to a much higher degree in developing economies, when compared to developed economies, following disasters of similar magnitude [10]. Hallegate, et. al. (2016) used WDI to find that floods reduced economic efficiency by disproportionately affecting the poor [11].

Duo, et. al. (2022) is of particular interest, as researchers used WDI to conclude that natural disasters significantly reduce carbon dioxide emissions [12]. Our analysis suggests that Maria had the opposite effect in Puerto Rico.

Other methods of studying disaster are also common. For example, the Harvard T.H. Chan School of Public Health used random surveys and data clustering to estimate that 4645 Puerto Ricans perished in the wake of Maria [13].

Relevant literature confirms some of our findings about Maria's effects in Puerto Rico. For example, Kenner, et. al. (2023) estimate that Maria destroyed over 80 percent of Puerto Rico's 2017 agricultural crop value [14]. Meanwhile, 10% of Puerto Rico's small business did not reopen by December 2018 and 40% of residents were unemployed or earning less than they did before Maria [15].

Structural damage and the economic conditions that followed Maria forced the Government of Puerto Rico to close 25% of public schools in the Commonwealth. This affected over 60,000 students [16]. Furthermore, 32% of young Puerto Ricans experienced food and water shortages and 17% of their homes did not have electricity 5 to 9 months after Maria. These conditions, in combination with an exacerbated exodus of healthcare professionals, worsened the Commonwealth's already poor healthcare outcomes [17].

DATA SET

Our dataset combines the complete World Development Indicators with all data between 1960 and 2023 in the Emergency Events Database. In total, our dataset contains 27,000,000 records.

Initially, we used a large Comma Separated Value ("csv") file to extract WDI data. We obtained this csv file by querying databank.worldbank.org.
The file was too large for our remote repository and every member of our team had their own WDI csv. To ensure consistency across workspaces and streamline analysis, we built the Pipeline to now extract data through the World Bank Indicators API ("API"). EM-DAT data is extracted from a csv file we obtained via public.emdat.be/data.

WDI contains 1496 attributes (Development Indicators) for 217 countries, with data between

1960 and 2023 for these attributes. The attributes belong to at least one of the following categories:

1. Economic Policy & Debt
2. Education
3. Environment
4. Financial Sector
5. Gender
6. Health
7. Infrastructure
8. Poverty
9. Private Sector & Trade
10. Public Sector
11. Social Protection & Labor
12. Social: health

Our EM-DAT selection contains 45 attributes and 25,530 records (disasters). EM-DAT has granularity of disaster-disaster type-location-effects. Of note, the Center for Research on the Epidemiology of Disasters indicates that disasters before 2000 are subject to reporting biases.

MAIN TECHNIQUES APPLIED

To determine which areas of social and economic development were permanently affected by Hurricane Maria in the Commonwealth of Puerto Rico, we employed the following data mining and statistical steps using a modular data pipeline built in Python.

1. Extract

The Pipeline begins by employing two functions to extract data from WDI and EM-DAT, using an unique function for each. `Extract_development_data` leverages the *wbgapi*[1] module to query the API and extract all Indicators for a specified country. `Extract_disaster_data` does the same for our EM-DAT csv file.

Each function expects a country's ISO3 Code ("PRI" for Puerto Rico) as an argument. After extraction, the functions build a Pandas DataFrame using their respective data. The DataFrames are then passed as arguments to functions in the Transformation step.

Pipeline users have the option of triggering a boolean variable to save these DataFrames as csv files (`save_to_csv`). We found these useful to verify trends as we conducted time-series analysis.

2. Transform

The DataFrames built in the previous step are then transformed by the following functions.

`Transform_development_data` receives the WDI DataFrame as an argument alongside the ISO3 Code of the selected country. Optional arguments include `df_min_year`, `df_max_year`, and `save_to_csv`. If the user does not change the default values for `df_min_year` (2007) and `df_max_year` (2023), this function will filter WDI Indicators to only include data for this time period.

`Transform_development_data` proceeds by cleaning the filtered WDI DataFrame using Pandas methods. The function eliminates Indicators where 51% of its years contain NULL values or where all years contain a value of 0. Next, the function uses backward fill, linear interpolation, and forward fill to handle any NULL values that remain. Finally, the transformed DataFrame is passed to a function that conducts time-series analysis on its Indicators.

`Transform_disaster_data` contains the same arguments as its WDI counterpart. Additionally, it contains the variable `min_total_affected` which is used to determine what constitutes a significant disaster. The default value is 500,000 affected individuals. The value intends to isolate Hurricane Maria in

[1] https://github.com/tgherzog/wbgapi.

the resulting DataFrame, but may be changed by Pipeline users to isolate other disasters.

As we focused on Puerto Rico and Hurricane Maria, `transform_disaster_data` proceeds by filtering the EM-DAT DataFrame to only include major hurricanes (Category 3 and above), and eliminating any hurricane that does not meet the significance threshold. Finally, the EM-DAT DataFrame is passed to the analytics function.

3. Analysis

Finally, the Pipeline concludes by using the transformed WDI and EM-DAT DataFrames to conduct time-series analysis using Matplotlib and Seaborn methods. `Generate_report` creates a plot for each Indicator and marks 2017 as the year Hurricane Maria arrived in Puerto Rico. It then returns a pdf file with all plots.

Additional methods within `Generate_report` distinguish between natural disasters that received a humanitarian and financial response from the United States, as determined by the "OFDA/BHA[2] Response" attribute in EM-DAT. As Puerto Rico is a territory of the United States, these methods ignore natural disasters that occurred in Puerto Rico.

We conclude our analysis by visually analyzing the report returned by this step in the Pipeline and share our findings in the following section.

KEY RESULTS

We conclude that Maria negatively and permanently affected the following areas of socioeconomic development in the Commonwealth:

1. Food Production and Nutrition

In our review of relevant literature, we found that Maria destroyed over 80 percent of Puerto Rico's 2017 agricultural crop value and that 32% of young Puerto Ricans experienced food insecurity months after Maria. Our time-series analysis suggests that Puerto Rico's domestic food supply has not recovered, which could have negative consequences in local nutrition and health outcomes.

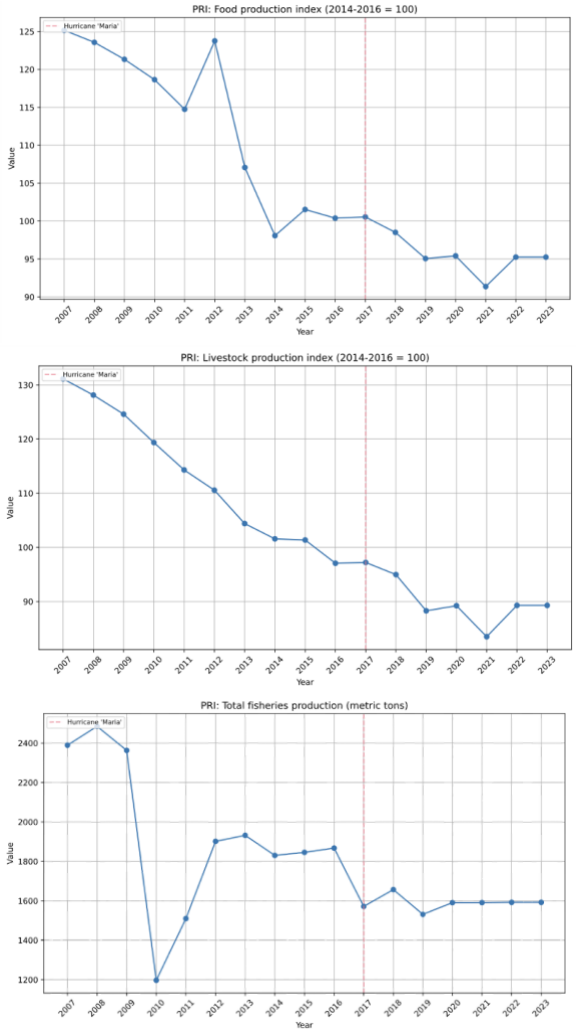


Figure 2. Puerto Rico: Food, Livestock, and Fisheries Production Indicators (2007-2023).

The Food Production and Livestock Production indexes are normalized to a value of 100 for the baseline time period of 2014-2016. Both

[2] The Bureau of Humanitarian Assistance is an American foreign aid agency.

Indicators trend downwards sharply after 2017 and stabilize at the 95 line (Food) and 90 line (Livestock) between 2019 and 2023. We find a similar trend for Fisheries Production. Together, these trends suggest that Maria permanently affected domestic food production in Puerto Rico.

2. Public Sentiment

In August 2019, Ricardo Rosselló became the first democratically elected Governor of Puerto Rico to resign. Among other things, protestors cited the death toll of Maria and the Rosselló Administration's management of disaster relief as reasons for their discontent.

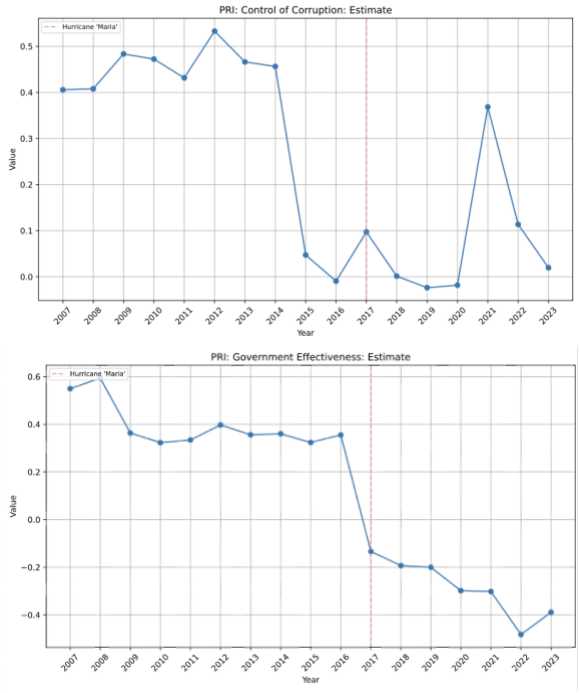


Figure 3. Puerto Rico: Public Sentiment Indicators (2007-2023).

These indicators measure public perception of corruption and effectiveness in government. Lower values suggest less favorable public sentiment.

For the Control of Corruption Indicator, we find that the post-Maria years continue a prolonged downwards trend. This aligns with the literature on the Summer of 2019 protests that ousted Governor Ricardo Rosselló. The positive spikes in 2017 and 2020 coincide with Maria and COVID-19, respectively, and are explained by the "Rally 'Round the Flag" Effect. The public puts aside political differences and supports the country's chief executive in times of crisis [18].

As for the Government Effectiveness Indicator, we find a stable trend line that plummets sharply after Maria. It has not recovered to pre-Maria levels as of 2023.

Together, these trends indicate an immediate need for officials in the Commonwealth to fix their reputation among Puerto Ricans since negative public sentiment is a leading indicator for political unrest [19].

3. Energy

Puerto Rico suffered the largest blackout in history after Maria. Literature shows that recovery in the power grid was slow and insufficient in the months that followed the hurricane. We find that this trend persists.

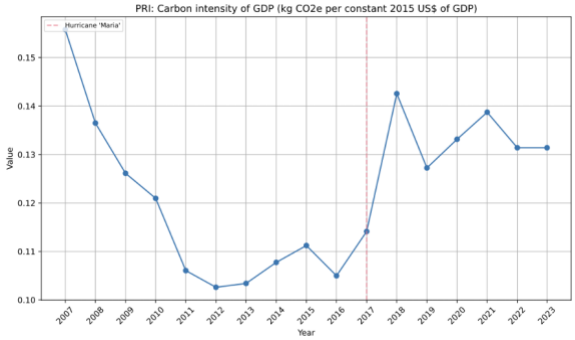


Figure 4. Puerto Rico: Carbon Intensity of GDP (2007-2023).

The plot in Figure 4 tracks the amount of carbon dioxide produced per unit of Gross Domestic Product. Lower emissions would suggest a decoupling of economic growth from carbon emissions. We find the opposite trend in Puerto Rico after Maria. This Indicator shoots upwards after the hurricane and has not reverted to pre-Maria levels.

For carbon intensity to be higher, either GDP decreased, or Puerto Rico grew its reliance on fossil fuels. Puerto Rico has experienced moderate GDP growth in recent years, and we find that Greenhouse Gas Emissions (Methane, Carbon Dioxide, and Nitrous Oxide) emissions increased following Maria.

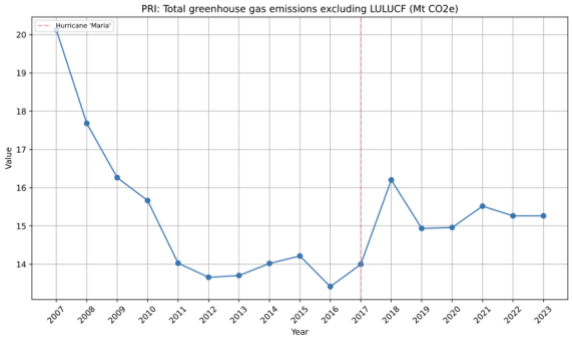
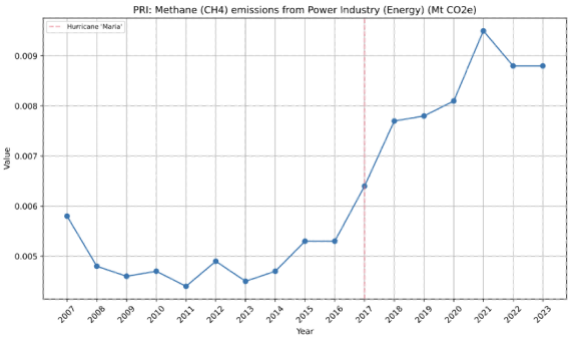


Figure 5. Puerto Rico: Total greenhouse gas emissions excluding LULUCF (2007-2023).

The Indicator in Figure 5 calculates the total emissions from sectors like Energy, Industry, and Transportation without considering the impact of land management practices on carbon sinks and sources. With these exclusions, it accurately captures emissions directly produced by human activity. We found that Maria had no permanent effect on Indicators measuring Greenhouse Gas Emissions in Industry or Transportation.



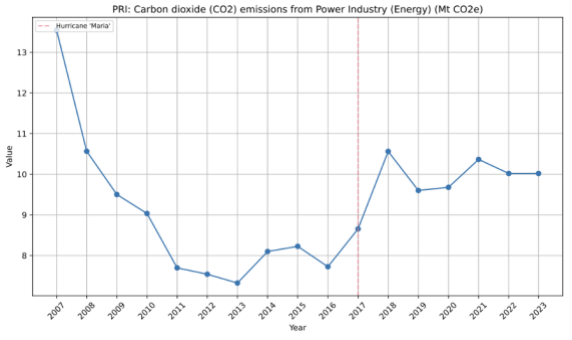


Figure 6. Puerto Rico: Greenhouse Gas Emissions from Power Industry (2007-2023).

Post-Maria trends in Greenhouse Gas Emissions are positively correlated with the Energy sector, particularly Methane and Carbon Dioxide, which shot up after Maria and stabilized at post-2017 levels.

Figures 4-6 allow us to conclude that Puerto Rico's power grid is less efficient and less green than it was before Hurricane Maria. This is a cause for concern as it suggests that a new significant storm would cause another large blackout.

4. Education

The literature finds that structural damage and the economic conditions that followed Maria forced the Government of Puerto Rico to close 25% of public schools in the Commonwealth. This affected over 60,000 students. Our time-series analysis suggests that the public school system has not recovered from the persistent effects of Maria.

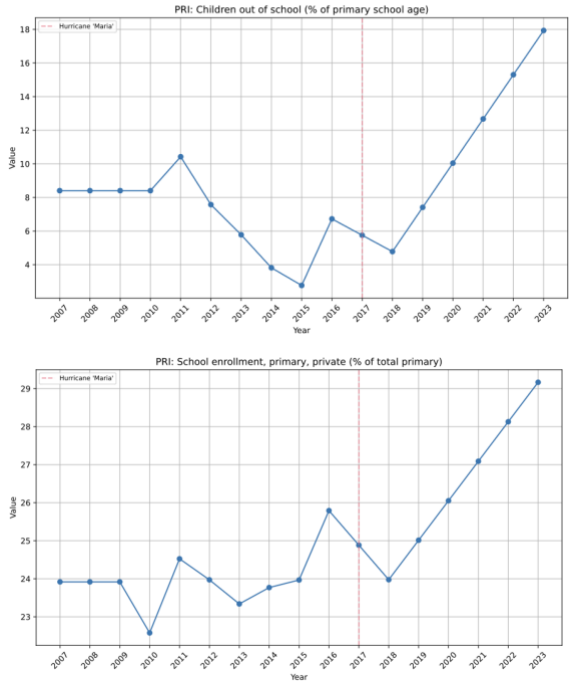


Figure 7. Puerto Rico: Primary School Enrollment (2007-2023).

In conjunction with the literature, Figure 7 suggests that Maria caused Puerto Rican children to leave formal K-12 education.

As the number of children out of school increases after Maria, so does the number of children enrolled in private schools.

The Government of Puerto Rico closed public school campuses in the wake of Maria. 40% of Puerto Ricans live under the federal poverty line [15]. In conjunction with Figure 7, these facts suggest that a reduction in school campuses, and public school quality, forced parents in Puerto Rico to enroll their children in private schools. Yet, many Puerto Ricans live in poverty and cannot afford private schools. Therefore, their children go without education.

As doctors and other educated professionals abandon Puerto Rico, children leaving formal education in the wake of Maria serves as an omen of an economic spiral. If Puerto Rico cannot replace its professional class, the Commonwealth's economy may become less sophisticated and come to depend more on low-wage industries, like tourism.

5. Economic Productivity

Finally, Puerto Rico may be experiencing early signs of said economic spiral. Figure 1 (see: INTRODUCTION) shows that Hurricane Maria caused deflationary pressure in the Commonwealth. This has not led to improved economic outcomes for Puerto Rican consumers.

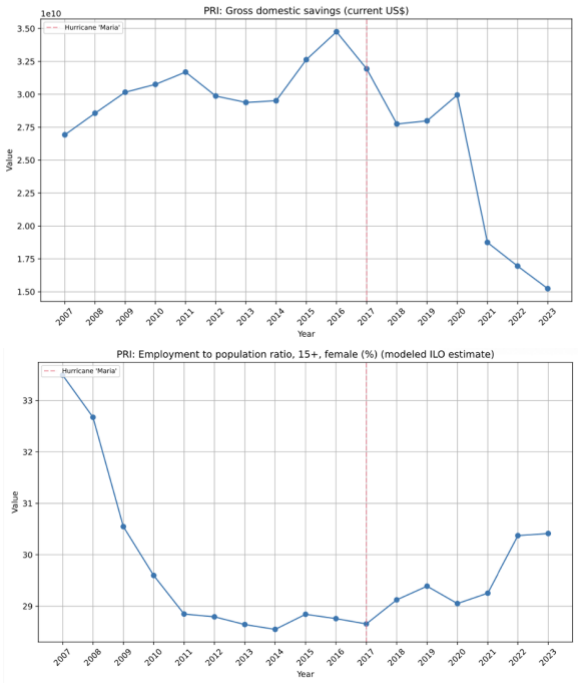


Figure 8. Puerto Rico: Savings and employed teenage girls (2007–2023).

The first plot in Figure 8 measures total savings in an economy after accounting for consumption expenditures. It suggests that Maria created compounding downwards pressure on savings, despite an ephemeral trend reversal due to the COVID-19 pandemic and in spite of deflationary pressures. Furthermore, Figure 8 suggests that Maria began an upwards trend in employed teenage girls that persists into 2023.

After Hurricane Maria, Puerto Rico is a poorer country where teenagers must seek employment. This may worsen the trends we found in

Education and compound a post-Maria economic spiral.

CONCLUSION

We tasked ourselves with finding which areas of social and economic development in the Commonwealth of Puerto Rico were permanently affected by Hurricane Maria. After designing a data pipeline that extracted, transformed, and analyzed data from the World Development Index and the Emergency Events database, we found five permanently affected areas:

1. Food Production and Nutrition
2. Public Sentiment
3. Energy
4. Education
5. Economic Productivity

APPLICATIONS

Our key findings suggest that there is no post hurricane world in Puerto Rico. 7 years after Maria, the Commonwealth struggles to recover across 5 crucial areas of socioeconomic development. While these findings point towards a somber future for the American territory, they also offer local and federal leaders actionable areas in which to focus recovery efforts.

We believe that the dynamics outlined in previous sections compound each other, and that unraveling a decades-long tangled web of problems requires closing the biggest wound first. Puerto Rico must fix its outdated, dirty, and inefficient power grid. After all, many of the struggles we documented trace back to the historic blackout that followed Maria's arrival to Puerto Rico.

ACKNOWLEDGMENTS

This project is dedicated to the people of Puerto Rico, who rose in protest in the Summer of 19 to demand better governance and persevere in the long shadow of that faithful September 2017 night. We hope they find The Post Hurricane World they deserve.

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