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Assessing the Fiscal Impact of Hurricanes on Counties in Florida

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handed in by

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Abstract

This thesis studies the effect of hurricanes on fiscal costs in Florida at the county level from 1993 to 2019. Using estimated damages derived from a wind field model, the analysis reveals that both expenditures and revenues significantly increase during the period in which a hurricane occurs. Moreover, these effects persist in subsequent periods. The increase in expenditures can mainly be attributed to costs related to the physical environment and public safety for disaster relief and recovery. This highlights the critical role of local governments in managing natural disasters, especially hurricanes. Meanwhile, the increase in revenues is largely attributable to federal and state grants, which partially offset the additional expenditures. This underlines the dependency of counties on state and federal resources for disaster response. Overall, the findings emphasize the importance of cooperation between local, state, and federal governments in responding effectively to natural disasters, particularly hurricanes.

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1 Introduction

Due to climate change, more extreme and unusual weather patterns impact economic activities by destroying infrastructure and crops. While some find a positive impact on economic growth (Loayza et al., 2012; Skidmore & Toya, 2002), a vast body of literature underlines the negative effect of natural disasters on the (local) economy (Acevedo, 2014; Cavallo et al., 2013; Noy & Nualsri, 2011; Strobl, 2011, 2012). Tropical storms are no exception. With global warming, tropical storms are likely to intensify (IPCC, 2023). In fact, the intensification of tropical cyclones can already be observed (Bhatia et al., 2022). The increase in economic losses caused by extreme events can partly be explained by demographic expansion and economic development in regions susceptible to disasters (Botzen et al., 2019). Florida is the epitome of such an area because it is densely populated and located in the hurricane-prone Atlantic basin (Barnes, 2012). This is why these storms pose a recurring threat.

Generally, we speak of hurricanes if a tropical cyclone in the Atlantic Basin achieves wind speeds of at least 119 km/h (Atlantic Oceanograohic and Meteorlogical Labaratory, 2023). Several atmospheric and marine conditions, such as ocean temperature, humidity, wind, and spin, must align for the formation of a tropical cyclone (Atlantic Oceanograohic and Meteorlogical Labaratory, 2023). Hurricanes, with an average cost of $ 22.8 billion per occurrence, are the main cause of destruction and deaths in the United States (US) caused by weather disasters (Office for Coastal Management, 2024). Since natural disasters are regarded as a public issue, they demand governmental intervention (Schneider, 1995).

Governments are responsible for delivering public goods and services such as public safety, infrastructure, and healthcare in the US. Therefore, the impact of natural hazards on fiscal costs has high policy relevance. Natural disasters, such as hurricanes, directly and indirectly impact fiscal costs through reconstruction expenses, emergency aid, and changes in tax revenues. Generally, the literature agrees on the increase of expenditures due to natural disasters (Miao et al., 2020; Noy et al., 2023; Ouattara & Strobl, 2013). These findings can similarly be observed in the US (Jerch et al., 2023; Miao et al., 2018, 2023). However, the methods used to analyze the fiscal impact and derive damages vary greatly. Due to the provision of emergency aid, relief efforts, and support for the rehabilitation of impacted areas, fiscal expenditures of US states are affected by natural disasters (Miao et al., 2018). Natural disasters may force governments to reallocate budgetary resources, diverting funding from planned projects to accommodate disaster spending (Benson & Clay, 2004). Governments often rely on reserves but may also tap into other revenue sources, such as federal assistance (Jerch et al., 2023). Furthermore, the macroeconomic consequences, such as the effects on earnings and job opportunities, can alter tax revenues and the government's financial resources (Deryugina, 2022). Hurricanes often disrupt business activities and damage assets, reducing property values and employment, which may lower local tax revenues (Davlasheridze et al., 2017; Hallstrom & Smith, 2005; Mohan & Strobl, 2021). At the same time, they may temporarily boost revenues due to recovery spending, such as increased sales tax revenues observed after major disasters (Baade et al., 2007; Miao et al., 2018). Several studies, however, find that the impact on expenditures is more pronounced (Miao et al., 2020; Ouattara & Strobl, 2013). Besides direct disaster-related costs, hurricanes lead to a significant increase in social costs such as medical spending and unemployment insurance costs (Deryugina, 2017). This is in line with the results of Miao et al. (2018) who show that additional state expenditure triggered by disasters include not only relief funds for disasters, but also public welfare assistance. Further, these costs are predominantly covered by federal transfers.

Florida's decentralized fiscal system places primary responsibility for public services and emergency response on local governments such as counties and municipalities since they are closer to environmental problems. Further, Botzen et al. (2019) underline the importance of accounting for geography in regional studies. Jerch et al. (2023) find that large hurricanes impact both revenues and expenditures on a municipality level significantly more compared to minor hurricanes using a panel fixed effects model based on data from the Census of Governments that is collected every five years. Additionally, they underline that the effect depends on demographic characteristics such as racial composition. Nevertheless, counties play a key role in disaster and hazard management due to greater access to state and federal resources compared to municipalities (McGuire & Silvia, 2010). Using presidential disaster declaration as an indicator for severe disaster events, Miao et al. (2023) find that hurricanes notably increase government expenses but decrease tax income in the US at the county level. Since the impact of hurricanes is higher than for floods, their results underline the relevance of understanding the impact of hurricanes on fiscal costs. However, they are not able to account for the degree of damage.

In this thesis, we fill this gap by analyzing the impact of hurricanes on the expenditures and revenues of local governments in the state of Florida at the county level from 1993-2019. Based on data from the Office of Economic and Demographic Research (2024), we evaluate the impact of hurricanes on both total expenditures and revenues accounting for varying degrees of damage. Compared to previous papers, we conduct a comprehensive analysis of expenditure and revenue categories and examine their proportions relative to total expenditures and revenues. The estimated degree of damage at the county level is calculated by using a hurricane destruction index popularized by Strobl (2011, 2012) which is based on a wind field model. It accounts for local characteristics by using population weights as a measure of damage potential. The hurricane destruction index allows us to control for different degrees of damage. To derive estimated damages at the point of interest, the index relies on hurricane best track data (HURDAT 2).

This thesis relates to several strands of literature. First, it contributes to the literature on the impact of extreme events on the economy (e.g. Acevedo, 2014; Benson and Clay, 2004; Loayza et al., 2012; Skidmore and Toya, 2002; Strobl, 2012) and, specifically, the US (e.g., Deryugina, 2017; Strobl, 2011). Secondly, it adds to the growing body of literature examining the fiscal impacts of natural hazards such as Lis and Nickel (2010), Melecky and Raddatz (2011, 2014), Noy and Nualsri (2011), and Ouattara and Strobl (2013), especially studies that focus on local impacts like Chen (2020), Jerch et al. (2023), Miao et al. (2018, 2020, 2023), and Noy et al. (2023). This thesis demonstrates that there are significant increases in both expenditures and revenues not only in the fiscal year the hurricane occurred but also in the following years. However, the impact varies across categories. Public safety and physical environment costs increase to provide emergency and disaster relief, manage resources, and control floods, while revenues increase mainly related to state and federal grants. Further, tax revenues increase which may be attributed to increased economic activity through post-disaster aid. Therefore, this thesis contributes to the discussion of disaster-driven changes in revenues, such as increased tax income from post-disaster recovery efforts (e.g. Baade et al., 2007; Miao et al., 2018), and expenditures (e.g. Deryugina, 2022; Miao et al., 2018, 2023) and highlights long-term shifts in fiscal structures. Further, it explores the fiscal resilience of (local) governments to disasters, including their ability to adapt through increased intergovernmental transfers or shifts in expenditure priorities (e.g. Chen, 2020; Lis and Nickel, 2010; Miao et al., 2020; Noy et al., 2023).

The remainder of this thesis is structured as follows: Section 2 provides a background of hurricanes and the fiscal system in Florida. Then, Section 3 introduces the data on which the analysis is based, followed by Section 4 which gives an overview of the method used for the statistical analysis. Section 5 presents the results. Finally, Section 6 discusses the findings and concludes.

2 Background

2.1 Hurricanes

Generally, a tropical cyclone in the Atlantic Basin is referred to as a hurricane once it reaches wind speeds of at least 119 km/h (Atlantic Oceanograohic and Meteorlogical Labaratory, 2023). Tropical cyclones are characterized by a low-pressure system with cyclonic winds and draw their energy from vertical temperature differences. The formation of a tropical cyclone requires the alignment of several atmospheric and marine conditions, including ocean temperature, humidity, wind, and spin (Atlantic Oceanograohic and Meteorlogical Labaratory, 2023). Based on the maximum sustained wind speed, you can divide hurricanes into five categories also known as the Saffir-Simpson Scale (SS Scale). The scale is used to estimate property damages. The main hazards related to hurricanes are storm surges, storm tides, heavy rainfall, flooding, high winds, rip currents, and tornadoes (National Hurricane Center and Central Pacific Hurricane Center, 2024a). Florida has a long history of hurricanes, as its coastal location makes it particularly vulnerable to these storms (Malmstadt et al., 2009). Further, the growth of the state and development of infrastructure have amplified the damage potential (Barnes, 2012). The state has experienced numerous major hurricanes, with some of the most notable events occurring in the early 20th century, such as the 1928 Okeechobee hurricane and the 1935 Labor Day hurricane (Barnes, 2012). In more recent decades, hurricanes such as Andrew (1992), Charley (2004), and Irma (2017) have caused significant damage. In the past, a rise in the severity of hurricanes has been observed (Emanuel, 2005). For example, the hurricane season in 2017 had several hurricanes such as Harvey, Irma, and Maria which led to high damages (Inserra et al., 2018). The insights gained from Hurricane Andrew marked a pivotal moment for increasing investments in hurricane preparedness (Barnes, 2012). Despite developing advanced systems for forecasting and emergency response, the threat of hurricanes remains a major concern for the state.

2.2 Fiscal system

Florida's fiscal system operates under a decentralized structure, where significant responsibility lies with local governments. These governments include counties, municipalities, and special districts. Each plays an important role in the delivery of public services and the management of public funds. While the state and federal governments provide significant support, local governments are the first responders in any emergency. Counties play a key role in disaster and hazard management due to their access to state and federal resources (McGuire & Silvia, 2010). Each of Florida's 67 counties has its own elected government, typically consisting of a Board of County Commissioners, which oversees the budget, taxation, and spending for the county (Florida Legislature, 2024; Jewett, 2014). Counties are responsible for providing essential services such as public safety, healthcare, education, infrastructure, and emergency management (Florida Association of Counties, 2024).

One of the critical responsibilities of counties is disaster preparedness and response, particularly in relation to hurricanes (FEMA, n.d). Each county is required to have an emergency management plan in place, which outlines the steps to be taken before, during, and after a hurricane or other natural disasters (FEMA, 2010). This plan typically includes warning, coordinating evacuation procedures, logistic management, medical services, and recovery (FEMA, 2010). After a hurricane, counties also rely on state and federal assistance to cover the costs of recovery, which can include rebuilding homes, businesses, and public facilities, as well as supporting displaced populations (FEMA, n.d; National Association of Counties, 2019). Their ability to respond effectively depends on having the appropriate financial resources and the authority to manage them. In some cases, counties may need to tap into reserve funds, apply for state or federal disaster grants, or issue bonds to finance recovery efforts (Jerch et al., 2023; National Association of Counties, 2019; Painter, 2020). For instance, if Presidential Disaster Declarations are made after a natural disaster, local governments may receive reimbursements from the federal government through programs such as the FEMA's Public Assistance (Jerch et al., 2023; Kousky & Shabman, 2012). The Division of Emergency Management in Florida provides support by coordinating with federal agencies such as the Federal Emergency Management Agency (FEMA) to ensure that local governments have the resources they need to manage both the immediate and long-term impacts of hurricanes (Division of Emergency Management, n.d.).

3 Data and descriptive statistics

In this section, we introduce the data on which the analysis is based. First, we focus on fiscal data at the county level. Then, we describe the data that is used for the hurricane destruction index. At last, we present the summary statistics.

3.1 Fiscal variables

To obtain data on county fiscal expenditures and revenues in Florida, we rely on data from the Office of Economic and Demographic Research. By state law, local governments must report expenditures and revenues on an annual basis with fiscal year-end September 30 (Florida Legislature, 2024; Office of Economic and Demographic Research, 2024). The data is publicly available for all 67 counties in Florida from 1993-2023 and is created according to the yearly published guide from the Office of Economic and Demographic Research (2019). We create a panel dataset based on this data. The analysis in this thesis is based on data from 1993 to 2019 as a change in reporting practices in 2020 affects the comparability with earlier reports (Office of Economic and Demographic Research, 2024). The impact of COVID-19 further affects the analysis after 2020. Besides that, Jacksonville (County Duval) which is organized in a consolidated city-county form is excluded due to the difference in government form. Therefore, our dataset consists of 66 counties with annual data from 1993-2019.[1] The reports include detailed information on state expenses and revenues categorized in nine[2] respectively seven[3] account classes (Office of Economic and Demographic Research, 2024). We adjust the expenditure and revenue data for inflation using the Consumer-Price Index from the U.S. Bureau of Labor Statistics (2024).

3.2 Hurricanes

The Atlantic Hurricane Database includes detailed reports on hurricanes since 1851. The best track data, HURDAT, provides a detailed record of tropical cyclones throughout their lifetime, including their location, intensity, type, and size, based on a com-

[1] The dataset is not balanced due to the unavailability of data for the county Jefferson in 1999 and 2018 and for Suwannee in 1993.

[2] General government services, public safety, physical environment, transportation, economic environment, human services, culture & recreation, other uses & non-operating, and court-related expenditures

[3] Taxes; permits, fees, & special assessments; intergovernmental revenue; charges for services; judgments, fines & forfeits; miscellaneous revenue, and other sources

prehensive post-storm analysis of all available data (National Hurricane Center and Central Pacific Hurricane Center, n.d). It is the basis for calculating hurricane damages in this thesis (National Hurricane Center and Central Pacific Hurricane Center, 2024b). The Atlantic Hurricane Database is regarded as the most comprehensive hurricane database for the North Atlantic region (Elsner & Jagger, 2004). There are no significant differences between the revised version HURDAT 2 and the retired version HURDAT (Hurricane Research Division, 2023). However, the revised version contains more information on the best track of the hurricanes (Landsea, 2022). For all storms between 1993 and 2019, data on the location and intensity of tropical cyclones in the North Atlantic Basin (in six-hour intervals) is utilized to match the data on fiscal expenditures.[4] To obtain more detailed information on location, we refine the data by interpolating it to two-hour intervals.

In addition to data on the intensity and location of hurricanes, population data is used as weights to estimate hurricane destruction in counties (see Section 4.1). Under the assumption that in more populated areas there is more infrastructure that can be damaged, population estimates can be used to reflect damage potential. We use the census tract population data and the corresponding tract shape data from Manson et al. (2023). The dataset includes the total population of census tracts for the years 1990, 2000, 2010, and 2020 standardized to the year 2010. We linearly interpolate the population data to obtain intercensal estimates. To exclude the effect of migration due to hurricanes in the fiscal year, we use the pre-period population data as weights. The same dataset is used to calculate expenditure and revenue data in per capita terms.

3.3 Descriptive statistics

Table 3.1 shows the descriptive statistics for our panel dataset consisting of 66 counties for the time period 1993-2019.[5] Expenditures and revenues are calculated in per capita terms and are inflation-adjusted. Total mean expenditures of USD 1'867.94 per capita and mean revenues of USD 1'954.57 per capita are similar in size. This corresponds to our understanding due to the balanced budget requirement (Florida Legislature, 2024). However, there are sizeable differences in the different categories.

Mean public safety of USD 468.88 per capita is the largest expenditure category with 26% of total expenditures. It consists of costs for law enforcement, fire control, emergency and disaster relief, and other expenses related to public safety. Other uses and non-operation costs explain 19% with mean costs of USD 360.65 per capita. The ma-

[4] We use data from 1983 until 2019 in the analysis with lagged effects.
[5] Note that we use the fiscal year as reference.

Table 3.1: Summary statistics for fiscal variables

	Mean	Share	Max	Min	SD
Total expenditures	1'867.94	1.00	5'877.81	594.98	789.64
General government services	345.45	0.19	1286.21	65.31	156.50
Court-related expenditures	54.14	0.03	821.30	0.13	35.75
Public safety	468.88	0.26	2171.39	32.54	208.44
Physical environment	187.11	0.10	1566.92	2.49	156.12
Transportation	246.39	0.14	1865.12	45.34	162.16
Economic environment	61.60	0.03	650.30	0.03	72.65
Human services	86.24	0.04	1799.17	3.11	162.77
Culture and recreation	68.69	0.04	466.98	1.43	55.76
Other uses and non-operating	360.65	0.19	2136.08	1.03	267.86
Total revenues	1'954.37	1.00	6'242.72	636.39	844.27
Taxes	633.85	0.33	2123.80	181.96	283.02
Permits, fees, and special assessments	45.21	0.02	500.65	0.38	58.31
Intergovernmental revenue	345.71	0.19	2021.52	62.82	222.35
Charges for services	360.64	0.18	1881.69	6.62	301.58
Judgments, fines, and forfeits	16.63	0.01	553.23	0.04	22.06
Miscellaneous revenues	123.46	0.06	980.91	0.75	114.32
Other sources	430.08	0.21	3122.23	4.58	334.08

Note: This table shows the mean, share, maximum, minimum, and standard deviation of the fiscal variables in USD from the Office of Economic and Demographic Research (2024). The annual expenditures and revenues are shown in per capita terms and are inflation-adjusted.

jority of these expenditures are interfund transfers which are shifted amounts between funds within the county. General government expenditures (not court-related) are the third biggest category with a mean cost of USD 345.45 per capita which corresponds to 19% of total expenditures. Costs related to the physical environment consist of not only garbage, water, and sewer services, but also expenses for flood and stormwater control. Mean costs for the physical environment are USD 187.11 per capita. Further, expenditures related to transportation explain 14% of total expenditures with average costs of USD 246.39. Court-related expenditures, culture and recreation, economic environment, and human services explain a smaller part of total expenditures.

A similar pattern is visible in the distribution of the revenue categories. Taxes make up 33% of total revenues with a mean tax income of USD 633.85 per capita. Similar to expenditures, the second largest category is revenue from other sources of USD 430.08 which mainly consists of non-operating interfund group transfers[6] and debt proceeds. Furthermore, charges for services, with USD 360.64 per capita, are closely followed by mean intergovernmental revenues of USD 345.71 per capita. Mean miscellaneous revenues, permits, fees and special assessments, and judgments, fines, and forfeits are comparably smaller in size. Besides differences across the categories, there are also differences across counties and/or years which is visible by comparing the maximum

[6] Interfund transfers refer to the movement of funds within a governmental unit (Pasco County, 2021).

and minimum of the different categories. Further, Figure A.1 depicts the distribution of the categories as a share of total expenditure and revenues in more detail. We exploit these differences by analyzing whether part of the variation can be explained by hurricane damage.

Table 3.2 presents an overview of the hurricanes that affect the counties in the state of Florida during the time of the analysis. For the analysis, we use wind speeds that exceed the SS Scale category 1 (≧ 119 km/h). There were 19 hurricanes that reached wind speeds of at least 119 km/h in one of the counties. On average, the maximum sustained wind speed for these hurricanes is 148.43 km/h. In total, 55 of the 66 counties were affected in Florida during the time of the analysis. The maximum local wind speeds are estimated as explained in Section 4.1. The highest estimated wind speeds were reached by Hurricane Michael in October 2018 (fiscal year 2019). Hurricane Michael reached wind speeds up to 214 km/h in the state of Florida.

Table 3.2: Overview of hurricanes

Hurricane	Year	Month	Max WS	Counties affected
ELENA	1985	9	148.8	005, 033, 037, 045, 091, 113, 131
ANDREW	1992	8	193.6	011, 015, 021, 027, 043, 051, 055, 071, 085, 086, 087, 093, 099, 115
ERIN	1995	8	146.0	009, 043, 055, 061, 085, 093, 097, 099, 105, 111
OPAL	1995	10	133.3	033, 091, 113, 131
DANNY	1997	7	128.2	033
EARL	1998	9	135.6	005, 013, 037, 045, 063, 091, 131, 133
GEORGES	1998	9	127.8	087
CHARLEY	2004	8	182.4	015, 021, 027, 043, 049, 051, 055, 057, 071, 081, 087, 099, 103, 105, 115
FRANCES	2004	9	174.3	009, 011, 015, 021, 027, 043, 051, 055, 061, 071, 085, 086, 093, 095, 097, 099, 105, 111
IVAN	2004	9	157.4	033, 091, 113
JEANNE	2004	9	151.3	009, 011, 043, 051, 055, 061, 085, 093, 097, 099, 105, 111
DENNIS	2005	7	162.0	005, 033, 091, 113, 131, 133
KATRINA	2005	8	125.4	087
RITA	2005	9	136.5	087
WILMA	2005	10	141.9	011, 021, 043, 051, 061, 071, 085, 086, 087, 093, 099, 111
MATTHEW	2016	10	182.3	009, 011, 019, 021, 031, 035, 043, 051, 055, 061, 069, 083, 085, 086, 087, 089, 093, 095, 097, 099, 107, 109, 111, 117, 127
IRMA	2017	9	163.3	011, 015, 021, 027, 043, 051, 071, 086, 087
MICHAEL	2018	10	214.0	005, 013, 029, 033, 037, 039, 045, 059, 063, 065, 067, 073, 077, 079, 091, 113, 121, 123, 129, 131, 133
DORIAN	2019	9	162.8	009, 011, 043, 051, 061, 085, 086, 087, 093, 099, 111

Note: Overview of the hurricanes that affect the time period relevant for the analysis. The wind speed (WS) represents the maximum estimated wind speed (km/h) during the hurricane in one of the counties. The county codes are explained in Table A1.

4 Methodology

This section summarizes the methods used to estimate the impact of hurricanes on fiscal costs.

4.1 Hurricane destruction index

To account for regional differences in damages, we use the hurricane destruction index proposed by Strobl (2012). Damages are estimated based on the maximum wind speed of a hurricane. In addition to wind damages, heavy rainfall and storm surges cause flooding or landslides, which in turn cause destruction (Strobl, 2011). This means that hurricanes do not only cause damage in locations where they directly pass over but also in adjacent regions. However, both rainfall and storm surges are strongly linked to wind speed (Jiang et al., 2008; Musinguzi & Akbar, 2021). Using the interpolated hurricane best track data, we estimate local wind speeds to calculate the damage in the respective region.

First, we use a model that relies on the cyclostrophic wind and sustained wind velocity equation of Holland (1980). It has been verified for New England (Boose et al., 2001) and Puerto Rico (Boose et al., 2004). In line with Strobl (2012), we estimate wind velocity at any point of interest

$$V = GF\left[V_m - S\left(1 - sin\left(T\right)\right)\frac{V_h}{2}\right]\left[\left(\frac{R_m}{R}\right)^B exp\left(1 - \frac{R_m}{R}\right)^B\right]^{\frac{1}{2}}, \tag{4.1}$$

where V_m describes the maximum sustained wind speed in the hurricane. The angle T captures the hurricane's forward trajectory and a radial line extending from the center of the hurricane to the location of interest. V_h signifies the forward speed of the hurricane, R_m represents the radius of maximum winds, and R indicates the radial distance from the hurricane center to the point of interest. Further, F, S, and B serve as scaling parameters for surface friction, asymmetry resulting from the forward movement of the storm, and the configuration of the wind profile curve whereas G stands for the gust wind factor (see Strobl (2012) for more details). If we assume that a hurricane's energy release is proportionally linked to its wind speed (Emanuel, 2005), then we can estimate the hurricane destruction of a storm r in its lifetime τ at time t in a county i using the wind velocity V at location c calculated in Equation 4.1:

$$HD_{i,r,t} = \left(\sum_{c=1}^{C} \int_{0}^{\tau} V_{c,t}^{\lambda} w_{i,c,r,t} \, dr \right), V_{c,t} \geq 119 km/h. \tag{4.2}$$

Here, C includes all points of interest c within a county i, whereas the weights w represent the characteristics of the locality in terms of damage potential interpreted as the share of county population in $t-1$. λ links regional wind velocity to the degree of damage. Emanuel (2005) demonstrates that the relationship can be described as cubic ($\lambda = 3$) which is used for our analysis as in Strobl (2011, 2012).

If multiple hurricanes occur in a single year, we assume that not all physical damages can be repaired within the same fiscal year.[1] By summing damages, we risk overestimating their total impact, while averaging them could underestimate the severity of highly destructive hurricanes.[2] To address this, yearly damages within a county are defined by the maximum destruction caused by any hurricane H during the fiscal year:

$$HD_{i,t} = max \left(HD_{i,r,t} \right). \tag{4.3}$$

The destruction index $HD_{i,t}$ is used to analyze the influence of damages on fiscal cost.

4.2 Econometric specifications

To assess the impact of hurricanes on fiscal costs, we use two econometric models: a fixed effects model to analyze the effect on total expenditures and revenues and their categories and a seemingly unrelated regression (SUR) framework to analyze the impact on the share of expenditure and revenue groups. The methods are similar to Noy et al. (2023). The fixed-effect model is defined as follows:

$$logF_{i,t} = \beta_{HD} HD_{i,t} + \delta_t + \theta_i + \epsilon_{i,t}, \tag{4.4}$$

where $logF_{i,t}$ denotes the logarithm of the fiscal variable and $HD_{i,t}$ the hurricane destruction index in year t and county i. The fiscal variables of interest are total expenses, total revenues, and the different expenditure and revenue categories. All variables are inflation-adjusted and in per capita terms.

Further, we include year (δ_t) and county fixed effects (θ_i). Time fixed effects account for year-specific factors influencing fiscal variables such as budget rules or the enactment of new laws. On the other hand, county fixed effects control for time-invariant

[1] Using the maximum damage per year as a measure, even when reconstruction takes longer than a year, is not likely to affect the results since counties are rarely affected by hurricanes in consecutive years, as demonstrated in Table 3.2.

[2] We test the robustness of the results using mean and summarized damages in Section 5.3.2.

differences across counties. This, for example, captures variations in the fiscal composition of counties that may be tied to geographical characteristics, such as being situated in hurricane-prone regions. $\epsilon_{i,t}$ represents the error term. As usual in the literature, we use Driscoll-Kraay standard errors which are robust to spatial or temporal dependence across observations (Driscoll & Kraay, 1998). To assess the long-term effect of hurricane destruction on fiscal variables, we estimate the following model with the inclusion of the hurricane destruction index as lags (K):

$$logF_{i,t} = \sum_{k=0}^{K} \beta_{HD_k} HD_{i,t-k} + \delta_t + \theta_i + \epsilon_{i,t}. \tag{4.5}$$

We check the impact over a five and ten year period. To analyze the impact on the composition of the fiscal variables in relation to total expenditures and revenues, we calculate budget shares similar to Noy et al. (2023). Using the categories from the Office of Economic and Demographic Research (2024), we define the shares as follows:

$$B_{j,i,t} = \frac{E_{j,i,t}}{\sum_{j=1}^{J} E_{j,i,t}}, \tag{4.6}$$

where E is the expenditure in the expense category j. The same holds for the calculation of the revenue categories. Due to the shares being inherently linked, we use the SUR method with Prais-Winsten standard errors according to Blackwell (2005) which is based on Wooldridge (2002), Judge et al. (1988), and Baltagi and Baltagi (2008). Further, we control for panel-specific autocorrelation. The independent variables require restrictions across panels, whereas fixed effects vary by panel. This is reflected in the following set of equations:

$$B_{j,i,t} = \beta_{HD_j} HD_{i,t} + \delta_t + \mu_{j,i} + \epsilon_{j,i,t}. \tag{4.7}$$

Here, $\mu_{j,i}$ represents the panel-specific fixed effects for each expenditure and revenue category j in county i. Further, we control for time fixed effects. In the analysis, we also include lagged effects similar to Equation 4.5 which are not shown in Equation 4.7 for simplification.

The effect of the hurricane destruction index on fiscal variables can be interpreted as causal. Since the index is based on wind speed, it is not likely to be affected by economic changes. Further, hurricanes are random shocks. Despite warning systems, there is not ample time to prepare for hurricanes to mitigate damage or significantly influence fiscal variables.

5 Results

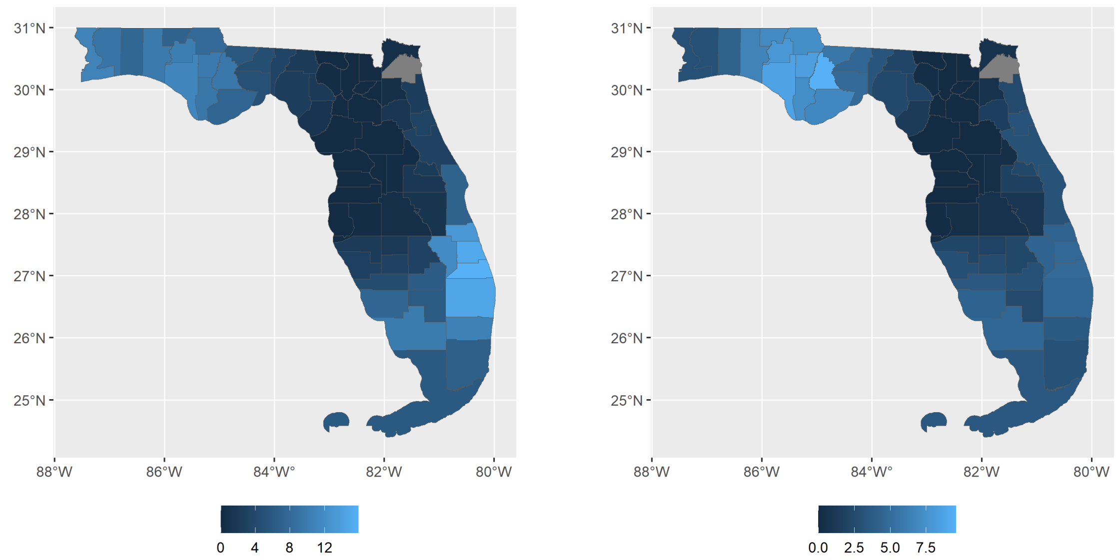
This section presents the empirical results of the impact of hurricane damages on fiscal costs in Florida at the county level. First, we analyze the distribution of hurricane damages using the hurricane destruction index. Then, we focus on the impact of hurricanes on expenditures and revenues.

5.1 Hurricane damages

We depict the estimated hurricane damage in the counties in Figure 5.1. Damages are calculated using the destruction index $HD_{i,t}$ as explained in Section 4.1. Note that damages are only calculated for hurricanes that reached local wind speeds of at least 119 km/h (SS Scale 1). The average destruction index for non-zero damages was 2.33 per county with estimated damages spanning from 0.01 to 9.55. In Figure 5.1a, we summarize the maximum cumulative hurricane destruction for each county in fiscal years 1993-2019. The lighter the shade, the more hurricane destruction the county experienced. The counties in Southeast and Northwest Florida experienced the highest damages. Generally, Northeast and Inland Florida are less prone to hurricanes compared to other regions. In Figure 5.1b, we only use the highest hurricane destruction index of each county over the time period. This allows us to analyze which regions are affected by severe hurricanes that cause high damage. Southwest Florida stands out with the highest damage indices. Comparing the graphs, the regions with the highest accumulated damages are not necessarily those, that experienced the highest damages in a single event. Martin County (FIPS code 085), located in the Southeast, experienced the highest estimated accumulated damages with a value of 15.88. The county was hit by several hurricanes, such as Frances, Matthew, Dorian, and Andrew, as depicted in Table 3.2. However, the estimated maximum damage of a single hurricane in the counties is lower than that of other counties that suffered the most severe impacts, measured by the hurricane destruction index. Bay (005), Calhoun (013), and Liberty (077), situated in the Northwest, are the counties that experienced the highest damages by a single hurricane event. Measured in the form of the hurricane destruction index, this equals to a value of approximately 9. The damage was caused by Hurricane Michael in October 2018 (fiscal year 2019). The figures demonstrate that there is variation in the distribution of damages not only over the years but also across counties. We use the differences in estimated damages measured in the form of the hurricane destruction index to analyze the effect on fiscal cost in the next section. The county of

Duval (gray), located in the less hurricane-prone area, is not included in the analysis due to the difference in government form as explained in Section 3.1.

Figure 5.1: Distribution of hurricane destruction across counties in Florida



(a) Accumulated hurricane destruction

(b) Maximum hurricane destruction

Note: The table illustrates the destruction index $HD_{i,t}$ for each county. Figure 5.1a summarizes the accumulated destruction over the years for each county, while Figure 5.1b depicts only the maximum hurricane destruction for each county. Duval shown in gray is excluded from the analysis.

5.2 Fiscal impact

First, we analyze the effect on total spendings and revenues. Then, we study the effect on different expenditure and revenue components to understand what drives the changes.

5.2.1 Total expenditures and revenues

Table 5.1 presents the estimated effect of damages caused by hurricanes on total log county expenditures and revenues in Florida in per capita terms. We use the fixed effects model from Equations 4.4 and 4.5 with Driscoll-Kraay standard errors as explained in Section 4.2. An increase in the hurricane destruction index of one unit leads, on average, to an increase in total per capita expenditures of 1.6%. The increase is significant at the 1% level. By including lagged effects, the impact on expenditures is even higher at 1.9% and significant at the 1% level in the fiscal year in which the

Table 5.1: Effect of hurricane damages on total expenditures and revenues

	Total expenditures			*Total revenues*		
	(1)	(2)	(3)	(4)	(5)	(6)
HD_t	0.016***	0.019***	0.018***	0.015***	0.017***	0.016***
	(0.006)	(0.006)	(0.007)	(0.005)	(0.006)	(0.006)
HD_{t-1}		0.021	0.020		0.020	0.018
		(0.013)	(0.014)		(0.015)	(0.016)
HD_{t-2}		0.009	0.008		0.009	0.007
		(0.012)	(0.013)		(0.012)	(0.014)
HD_{t-3}		0.016***	0.015**		0.015***	0.013**
		(0.006)	(0.007)		(0.004)	(0.005)
HD_{t-4}		0.018***	0.017***		0.010***	0.008
		(0.005)	(0.005)		(0.004)	(0.004)
HD_{t-5}		0.004	0.002		0.003	0.001
		(0.003)	(0.005)		(0.004)	(0.005)
HD_{t-6}			−0.002			−0.006
			(0.006)			(0.007)
HD_{t-7}			0.001			−0.002
			(0.009)			(0.008)
HD_{t-8}			0.001			0.004
			(0.010)			(0.008)
HD_{t-9}			−0.009			−0.011
			(0.009)			(0.009)
HD_{t-10}			−0.004			−0.003
			(0.008)			(0.010)
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,779	1,779	1,779	1,779	1,779	1,779
R^2	0.005	0.013	0.013	0.004	0.010	0.011

Significance-codes: **p<0.05; ***p<0.01

Note: This table reports the estimated impact of the hurricane damages using the hurricane destruction index on total per county expenditures and revenues in per capita terms using the fixed effects model with Driscoll-Kraay standard errors in parentheses. Columns 1 and 4 estimate the effect of damages on fiscal variables in the year of the hurricane, while columns 2 and 5, as well as columns 3 and 6, incorporate lagged effects of 5 and 10 years, respectively.

hurricane occurred. To calculate the average effect of a hurricane, we use the average hurricane damage which equals to 2.33 (excluding zero damage events). Using the mean damage, the average increase in total expenditures amounts to 4.53%. In the following, the average impact on fiscal variables using the mean non-zero damage is shown in square brackets. There is still a positive impact on expenditures in years t+1 and t+2 after the hurricane with 2.1% [5.01%] and 0.9% [2.12%], respectively. However, the effect is not significant for these two periods. In years t+3 and t+4 the impact is again significant with an average effect of 1.6% [3.80%] and 1.8% [4.28%] per unit increase in damages. By year t+5, the effect on fiscal expenditure diminishes. In Column 3, we add lagged effects for a ten-year period. The results remain similar in terms of impact and significance levels as in Column 2 for the first five years. For year six to ten, there is no significant impact on county expenditures on average.

The pattern is similar for the impact on total county revenues which is depicted in Columns 4 to 6. On average, county per capita revenues increase by 1.5% for a unit increase in damages in the fiscal year the hurricane hit the county. This equals to an increase of 3.56% in total revenues using the mean non-zero damage of 2.33. Again, the effect is not only highly significant without the inclusion of lagged effects in Column 4, but also in Columns 5 and 6 with an average effect of 1.7% [4.04%] and 1.6% [3.80%], respectively. Through the inclusion of lagged effects in Columns 5 and 6, it stands out that there is a long-term effect on total revenues. In years t+1 and t+2 the effect is positive, however, not significant. After that, the impact is highly significant in years t+3 and t+4 with an average effect of 1.5% [3.56%] and 1.0% [2.36%]. This is similar to the analysis with the inclusion of lagged effects for ten years. However, there are slight differences in the significance levels. In year t+5 and the following years, the impact of hurricane damage on total revenue diminishes. We visualize the change in total county revenues and expenditures of Columns 2 and 5 in Figure A.2.

5.2.2 Expenditure and revenue categories

To understand the changes in total expenditures and revenues, we split total expenditures into nine [1] and total revenues into seven[2] categories as defined by the Office of Economic and Demographic Research (2024). The number of observations varies for each category because some counties report zero revenue or expenditures for certain categories in some years. We estimate the fixed effects model with the inclusion of lags for five years for each expenditure and revenue category.[3]

Expenditure categories

Table 5.2 presents the results of the impact of hurricane damages on expenditure categories in per capita terms. Generally, there is a positive effect on the majority of expenditure categories not only in the year in which the hurricane hit but also for the following time periods. On average, public safety costs increase by 2.3% for a unit increase in the hurricane destruction index in the year the hurricane occurred. This

[1] General government services, public safety, physical environment, transportation, economic environment, human services, culture & recreation, other uses & non-operating, and court-related expenditures

[2] Taxes; permits, fees, & special assessments; intergovernmental revenues; charges for services; judgments, fines & forfeits; miscellaneous revenue, and other sources

[3] We include lags for five years since the effect on total revenues and expenditures diminishes in year t+5 (see Table 5.1).

Table 5.2: Effect of hurricane damages on expenditure categories

	General	Court	Safety	Phys. Env.	Transp.	Eco Env.	Hum. Serv.	Culture	Other
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
HD_t	0.026***	0.008	0.023***	0.023***	0.004	0.011	−0.001	0.030***	0.015
	(0.009)	(0.024)	(0.009)	(0.007)	(0.011)	(0.017)	(0.008)	(0.008)	(0.010)
HD_{t-1}	0.015	0.005	0.026**	0.028**	0.013	0.056	0.002	0.014	−0.015
	(0.018)	(0.009)	(0.011)	(0.014)	(0.017)	(0.039)	(0.012)	(0.021)	(0.026)
HD_{t-2}	0.020	−0.003	0.009	0.0005	−0.008	0.050	0.014	0.025	0.020
	(0.020)	(0.012)	(0.009)	(0.010)	(0.009)	(0.035)	(0.012)	(0.023)	(0.032)
HD_{t-3}	0.031**	−0.038	0.028***	0.007	0.020**	0.050	0.011	−0.008	0.044**
	(0.012)	(0.029)	(0.006)	(0.012)	(0.010)	(0.032)	(0.023)	(0.031)	(0.022)
HD_{t-4}	0.021***	−0.021	0.016***	−0.012	0.018	0.088	0.013	0.007	0.030**
	(0.007)	(0.037)	(0.006)	(0.007)	(0.015)	(0.046)	(0.022)	(0.023)	(0.012)
HD_{t-5}	0.006	−0.001	0.007	−0.010	−0.015	0.088***	0.001	0.006	0.015
	(0.012)	(0.016)	(0.005)	(0.009)	(0.009)	(0.027)	(0.025)	(0.021)	(0.014)
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,779	1,465	1,779	1,777	1,779	1,778	1,776	1,779	1,773
R^2	0.011	0.001	0.012	0.004	0.002	0.009	0.001	0.004	0.002

Significance-codes: **p<0.05; ***p<0.01

Note: This table reports the estimated impact of hurricane damage using the hurricane destruction index on log expenditure categories in per capita terms using the fixed effects model with Driscoll-Kraay standard errors in parentheses.

category includes costs related to law enforcement, fire control, emergency and disaster relief, and ambulance and rescue services. The effect is significant at the 1% level and is even higher in the following year with 2.6%. In year t+2, the effect decreases and is not significant. However, in years t+3 and t+4 there is still a significant positive effect on public safety costs with 2.8% and 1.6%, on average, before the effect diminishes. The impact is similarly visible for physical environment expenditures which comprise not only electric and water utility services but also flood control and resource management. In the fiscal year the hurricane strikes, physical environment costs increase by 2.3%, on average, for a unit increase in damages, which is significant at the 1% level. For the following year, the effect is significant at the 5% level with an effect size of 2.8% on average. Compared to public safety, the impact on physical environment costs diminishes by year t+2. Besides these two categories, there is a significant increase in general government services and culture and recreation costs in the year of the hurricane. On average, general government service costs increase by 2.6% per capita, which is significant at the 1% level. Similar to total expenditures, the increase is not significant in periods t+1 and t+2 but becomes significant in t+3 and t+4 with an average increase of 3.1% and 2.1%, respectively, for a one-unit increase in the destruction index. For culture and recreation costs, consisting of expenditures related to libraries, parks, and cultural services, there is a significant increase in the fiscal year of the hurricane with 3.0% for a unit increase in the index on average. However, we do not observe a lasting effect in the following periods. Costs related to transportation such as road facilities and airports are not significantly impacted by hurricanes in the first three periods. In year t+3, there is an average effect of 2.0% (significant at the 5% level). On the other hand, economic environment expenditures related to housing, urban, and industry development are positively affected by hurricanes. However, the effect is not significant except for five years after the hurricane. A unit increase in the destruction index leads to an average increase of 8.8%, which is significant at the 1% level. Similarly to that, other costs are also affected in the latter years. The category other includes not only interfund transfers but also non-operating interest expenses and bond payments. On average, other expenditures increase by 4.4% in year t+3 and 3.0% in year t+4. Both effects are significant at the 5% level. There is no significant effect on court-related and human services expenditures.

Revenue categories

The effect on revenue categories is depicted in Table 5.3. The two categories with a lasting increase are taxes and intergovernmental revenues. Taxes, on average, increase by 1.0% for a unit increase in hurricane damages in the year of the hurricane strike. The effect is even higher in the following periods with 1.7% in t+1 (significant at the 5% level) and 1.9% in t+2 (significant at the 1% level). The effect peaks in year t+3 with an average effect of 2.1%, which is significant at the 1% level. After that, the effect decreases. The impact of hurricane damage is even greater for intergovernmental revenues. For a unit increase in the hurricane damage index, intergovernmental revenues increase by 3.2% in the fiscal year of the hurricane, which is significant at the 5% level. The effect is not only visible in the year of the hurricane but up to three years after the hurricane. The highest impact on intergovernmental revenues is visible in the year after the event, with an average increase of 5.3%. The impact decreases in t+2 and t+3 and becomes insignificant in t+4. Besides these two revenue categories, there is a sizeable impact on charges for services and judgments, fines, and forfeits in the fiscal year in which the hurricane occurred. Judgments, fines, and forfeits decrease by 4.5%, which is significant at the 1% level. The effect on the smallest revenue category is only visible in the year in which the hurricane affected the county. Further, charges for services represent income from the services provided by the county government such as physical environment, transportation, public safety, and other services and increase by 2.2%, on average, in year t (significant at the 1% level). On the other hand, there is a significant decrease in charges for services in year t+2 with a mean effect of 1.8%. Compared to the previous revenue categories, there is no significant impact on permits, fees, and special assessments in the year the damages occurred. However, there is a positive effect on permits in year t+4 with 6.5% (significant at the 5% level) on average. Apart from the year the hurricane impacted the county, the effect is positive during other periods, although not statistically significant. This category mainly includes revenues related to building permits and impact fees for additional infrastructure and public facilities. The positive effect on miscellaneous revenues, including interest and other income, becomes apparent only in the long term, with an impact of 3.3% in year t+4 and 4.9% in year t+5. Both are significant at the 5% level. The impact on other revenues is generally positive, but lacks statistical significance.

Table 5.3: Effect of hurricane damages on revenue categories

	Taxes	Permits	Intergov.	Charges	Judge.	Miscell.	Other
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
HD_t	0.010	−0.031	0.032**	0.022***	−0.045**	0.045	0.024
	(0.005)	(0.030)	(0.014)	(0.005)	(0.020)	(0.045)	(0.017)
HD_{t-1}	0.017**	0.055	0.053**	0.003	−0.010	0.018	0.014
	(0.007)	(0.030)	(0.024)	(0.007)	(0.017)	(0.023)	(0.035)
HD_{t-2}	0.019***	0.039	0.026	−0.018***	−0.001	0.002	0.023
	(0.005)	(0.035)	(0.014)	(0.006)	(0.021)	(0.025)	(0.039)
HD_{t-3}	0.021***	0.044	0.019**	−0.0005	0.028	0.023	0.034
	(0.006)	(0.032)	(0.008)	(0.013)	(0.039)	(0.021)	(0.020)
HD_{t-4}	0.008	0.065**	0.006	0.014	−0.013	0.033**	0.003
	(0.005)	(0.032)	(0.008)	(0.012)	(0.045)	(0.016)	(0.013)
HD_{t-5}	0.0002	0.033	−0.001	0.007	−0.010	0.049**	0.027
	(0.004)	(0.032)	(0.011)	(0.012)	(0.021)	(0.021)	(0.023)
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,779	1,776	1,779	1,779	1,778	1,772	1,777
R^2	0.018	0.008	0.024	0.003	0.004	0.006	0.001

Significance-codes: **p<0.05; ***p<0.01

Note: This table reports the estimated impact of hurricane damage using the hurricane destruction index on log revenue categories in per capita terms using the fixed effects model with Driscoll-Kraay standard errors in parentheses.

5.2.3 Budget shares

To evaluate the effect on the categories in relation to total expenditures and revenue, we analyze budget shares. This allows us to identify whether shares have shifted and determine which categories are affected. We perform the analysis using the SUR framework with expenditure and revenue ratios as dependent variables.

Expenditure shares

Table 5.4: Effect of hurricane damages on expenditure shares

	General	Court	Safety	Phys. Env.	Transp.	Eco. Env.	Hum. Serv.	Culture	Other
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
HD_t	0.003	-0.003	0.008***	0.002**	-0.003	-0.002	-0.003**	-0.002	-0.001
	(0.002)	(0.001)	(0.003)	(0.001)	(0.003)	(0.001)	(0.001)	(0.001)	(0.002)
HD_{t-1}	0.007**	-0.005**	0.010**	0.001	-0.003	-0.005**	-0.006***	-0.005***	0.002
	(0.003)	(0.002)	(0.004)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
HD_{t-2}	0.011***	-0.006**	0.006	-0.001	-0.004**	-0.005**	-0.006***	-0.004	0.005
	(0.003)	(0.003)	(0.005)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.003)
HD_{t-3}	0.008**	-0.006**	0.007	-0.003**	0.001	-0.004	-0.005**	-0.004**	0.006**
	(0.004)	(0.003)	(0.005)	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)	(0.003)
HD_{t-4}	0.006	-0.006**	0.004	-0.002	0.001	-0.004	-0.005**	-0.003	0.007**
	(0.004)	(0.003)	(0.005)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)
HD_{t-5}	0.004	-0.003	0.002	-0.002	-0.001	-0.002	-0.003	-0.001	0.004
	(0.003)	(0.002)	(0.004)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.003)
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,779	1,465	1,779	1,777	1,779	1,778	1,776	1,779	1,773

Significance-codes: **p<0.05; ***p<0.01

Note: This table reports the estimated impact of hurricane damage using the hurricane destruction index on expenditure budget shares as defined in Equation 4.7. We use the SUR framework with Prais-Winsten standard errors in parentheses.

Table 5.4 presents the results for expenditure shares. Public safety and physical environment expenditure ratios significantly increase in the period in which the hurricane occurred. On average, the public safety ratio increases by 0.8 percentage points (pp) for a unit increase in hurricane damages, which is significant at the 1% level. The effect is lower for the physical environment share with 0.2 pp. In the period after the hurricane, there is still a significant impact on the public safety ratio with 1.0 pp on average. A positive effect is also visible in periods after that but not statistically significant. Besides that, the share of general expenses increase in the period after a storm by 0.7 pp on average (significant at the 5% level). The significant impact of hurricane damages is also visible in year t+2 with 1.1 pp and 0.8 pp in year t+3. On the other hand, there is a decrease in most other ratios. The share of human services expenditures decrease by 0.3 pp in the year the hurricane occurred (significant at the 5% level). The effect is not only significant in the year the hurricane occurred but also for the following four periods. Furthermore, there is a mean decrease in the court-related expenditure ratio of 0.6 pp. The effect is significant at the 5% level from year t+1 until t+4. Similar to court-related expenditures, the share of culture and recreation expenses decreases. However, the effect is only significant for two periods, t+1 and t+3.

Revenue shares

Table 5.5 depicts the results for revenue shares. In the period in which the hurricane occurred, there is a negative trend in all revenue ratios except for taxes and intergovernmental revenues. However, the impact is only significant for revenues from permits, fees, and special assessments with 0.9 pp on average. In the following year, the impact is similar except for slight changes in significance levels. The intergovernmental revenue ratio increases, on average, by 0.7 pp for a unit increase in hurricane damages (significant at the 5% level). There is still a positive effect on the tax ratio, however, not significant. Further, the other budget shares are negatively affected. On average, revenues from permits, fees, and special assessments decrease by 0.6 pp for a unit increase in hurricane damages (significant at the 1% level). The effect persists until t+4. The impact is similar for judgments, fines, and forfeits but only lasts until t+2.

Table 5.5: Effect of hurricane damages on revenue shares

	Taxes	Permits	Intergov.	Charges	Judge.	Miscell.	Other
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
HD_t	0.004	-0.003**	0.005	0.000	-0.003	-0.001	-0.002
	(0.003)	(0.001)	(0.003)	(0.001)	(0.002)	(0.002)	(0.003)
HD_{t-1}	0.005	-0.006***	0.007**	-0.002	-0.007**	-0.001	0.001
	(0.006)	(0.002)	(0.003)	(0.002)	(0.003)	(0.004)	(0.004)
HD_{t-2}	0.010	-0.007***	0.001	-0.004	-0.008**	0.001	0.006
	(0.007)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)
HD_{t-3}	0.012	-0.008***	-0.001	-0.003	-0.007	0.002	0.003
	(0.007)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)
HD_{t-4}	0.010	-0.007***	0.000	0.001	-0.006	-0.000	0.003
	(0.007)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)
HD_{t-5}	0.008	-0.002	-0.001	0.001	-0.004	-0.003	0.000
	(0.005)	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.004)
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,779	1,776	1,779	1,779	1,778	1,772	1,777

Significance-codes: **p<0.05; ***p<0.01

Note: This table reports the estimated impact of hurricane damage using the hurricane destruction index on revenue budget shares as defined in Equation 4.7. We use the SUR framework with Prais-Winsten standard errors in parentheses.

5.3 Robustness check

To assess the robustness of the results we perform checks on the baseline regression of total county expenditures and revenues.

5.3.1 Hurricane categories

To calculate the hurricane destruction index, we restricted our sample to include only damages for hurricanes with estimated wind speeds of at least 119 km/h (SS Scale 1). We re-estimate the model for different hurricane categories on the SS Scale in Panel A in Tables 5.6 and 5.7. The columns labeled SS 2+ represent damages caused by hurricanes of category 2 or higher, while SS 3+ includes only those caused by category 3 hurricanes and above. Compared to our baseline model in Table 5.1, the average impact of hurricane damage is even higher on both total county expenditures and revenues. This corresponds to our understanding since higher damages lead to higher impacts on fiscal variables. First, we compare the results for using category 2 hurricanes. In the period in which the hurricane occurred, total county expenditures increase by 2.1%, on average, for a unit increase in the destruction index. The impact is similar for revenues with 2.2% on average. Both effects are significant at the 1% level. The increase in revenues and expenditures is visible not only for year t but also for the following four years. It peaks in the year after the hurricane for both expenditures and revenues with 2.8%, on average, for a unit increase in the hurricane destruction index (significant at the 1% level). The effect diminishes in t+5. For hurricanes reaching at least category 3, the effect is similar as for SS 2+ in year t with 2.0% for expenditures and 2.2% for revenues. However, we do not see a significant effect in the years after the hurricane occurred. This can be explained by the small number of counties that were affected by these types of hurricanes during the period covered in this thesis.

5.3.2 Maximum damages

We use the maximum damage caused by a hurricane for each county in a year to calculate the hurricane destruction index. In other words, we only use the most damaging hurricane each year if there are several hurricanes. This is based on the assumption, that not all damages can be fixed within a year. Therefore, accumulated damages would likely overestimate damages since the impact of several small hurricanes is likely smaller compared to one intense hurricane, whereas mean damages could underestimate damages due to the dilution of the effect of highly damaging hurricanes. We perform a robustness check using the mean hurricane destruction index and accumulated hur-

Table 5.6: Robustness: Effect of hurricanes on total expenditures

	A: Categories		*B: Index*		*C: Weights*	*D: Trends*
	SS 2+	SS 3+	Sum	Mean	Cubic WS	Leads
HD_{t+1}						0.008
						(0.005)
HD_t	0.021***	0.020***	0.015***	0.017***	0.015***	0.017***
	(0.005)	(0.004)	(0.004)	(0.007)	(0.005)	(0.006)
HD_{t-1}	0.028***	0.005	0.013**	0.018	0.013	
	(0.006)	(0.011)	(0.006)	(0.015)	(0.008)	
HD_{t-2}	0.014	0.010	0.005	0.004	0.002	
	(0.008)	(0.016)	(0.007)	(0.013)	(0.007)	
HD_{t-3}	0.014**	0.011	0.011***	0.014**	0.007	
	(0.007)	(0.014)	(0.003)	(0.007)	(0.004)	
HD_{t-4}	0.018***	0.005	0.014***	0.015***	0.008**	
	(0.005)	(0.005)	(0.003)	(0.005)	(0.004)	
HD_{t-5}	0.004	-0.002	0.005	-0.000	0.002	
	(0.005)	(0.003)	(0.002)	(0.004)	(0.003)	
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,779	1,779	1,779	1,779	1,779	1,779
R^2	0.016	0.005	0.010	0.008	0.010	0.006

Significance-codes: **p<0.05; ***p<0.01

Note: This table reports the results of the robustness tests. We use the fixed effects model with Driscoll-Kraay standard errors in parentheses to estimate the impact of hurricane damages on total county expenditures in per capita terms. The model includes lags for five years. Panel A checks the robustness of the results for different hurricane categories. Columns named SS 2+ use hurricanes that reach estimated wind speeds of at least category 2 on the SS Scale, while columns named SS 3+ include only hurricanes of category 3 or higher. In Panel B we estimate the model by using hurricane damage indices calculated using sum and mean damages per year. Panel C tests the robustness of the results by calculating the index without population weights. Panel D tests pre-trends in the fiscal variables by including leads.

ricane destruction index per year and county as a damage measure. The results are depicted in Panel B in Tables 5.6 and 5.7. Compared to the baseline regression in Table 5.1, the estimated coefficients are similar in size and significance levels for both revenues and expenditures. On average, total per capita expenditures increase by 1.5% using the accumulated and 1.7% using the mean damage index in the period of the hurricane. This is slightly smaller compared to the baseline regression with 1.9%. This corresponds to our understanding since the effect of an extreme hurricane is diluted by using mean and summarized damage measures (see Section 4.1). The estimated effect on total county revenues is similar to that observed for expenditures. Using the accumulated damage index, revenues increase by 1.2%, while for the mean, revenues increase by 1.5% which is smaller than the baseline model with 1.7% on average. As expected, the same pattern is visible in the subsequent periods.

Table 5.7: Robustness: Effect of hurricanes on total revenues

	A: Categories		*B: Index*		*C: Weights*	*D: Trends*
	SS 2+	SS 3+	Sum	Mean	Cubic WS	Leads
HD_{t+1}						0.010
						(0.006)
HD_t	0.022***	0.022***	0.012***	0.015**	0.011**	0.015***
	(0.003)	(0.005)	(0.004)	(0.006)	(0.005)	(0.006)
HD_{t-1}	0.028***	0.002	0.015	0.015	0.010	
	(0.010)	(0.017)	(0.008)	(0.016)	(0.009)	
HD_{t-2}	0.017	0.004	0.007	0.002	0.003	
	(0.009)	(0.015)	(0.007)	(0.013)	(0.007)	
HD_{t-3}	0.016***	0.008	0.011***	0.014***	0.008***	
	(0.005)	(0.009)	(0.002)	(0.005)	(0.003)	
HD_{t-4}	0.008**	−0.001	0.008***	0.006	0.003	
	(0.004)	(0.004)	(0.003)	(0.004)	(0.003)	
HD_{t-5}	0.003	−0.008***	0.004	−0.001	0.0004	
	(0.004)	(0.003)	(0.003)	(0.004)	(0.003)	
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,779	1,779	1,779	1,779	1,779	1,779
R^2	0.016	0.006	0.008	0.006	0.006	0.005

Significance-codes: **p<0.05; ***p<0.01

Note: This table reports the results of the robustness tests. We use the fixed effects model with Driscoll-Kraay standard errors in parentheses to estimate the impact of hurricane damages on total county revenues in per capita terms. The model includes lags for five years. Panel A checks the robustness of the results for different hurricane categories. Columns named SS 2+ use hurricanes that reach estimated wind speeds of at least category 2 on the SS Scale, while columns named SS 3+ include only hurricanes of category 3 or higher. In Panel B we estimate the model by using hurricane damage indices calculated using sum and mean damages per year. Panel C tests the robustness of the results by calculating the index without population weights. Panel D tests pre-trends in the fiscal variables by including leads.

5.3.3 Unweighted index

To test the robustness of the results received by using the population-based destruction index, we re-estimate the baseline regression without the weights in Panel C in Tables 5.6 and 5.7. Without the population weights, the hurricane destruction index represents the cubic wind speed. Compared to the baseline model, the estimated effects are slightly smaller. Nevertheless, there is still a positive and significant effect on fiscal variables for both county expenditures and revenues in comparison with the baseline regression (in parentheses). On average, total expenditures increase by 1.5% (1.9%), whereas revenues increase by 1.1% (1.7%) for a unit increase in damages measured in the form of cubic wind speeds. The effects are significant at the 1% and 5% level, respectively. In the subsequent years, there is also a positive effect. The pattern in significance level and size is similar to the baseline model, however slightly smaller. For expenditures, the effect in the following five years varies between 0.2% and 1.3% (0.4% and 2.1%), while revenues increase between 0.0% and 1.0.% (0.3% and 2.0%) for a unit increase in the index. The main reason is that the population-weighted index gives more weight to hurricanes that affect a higher share of the county population with high wind speeds.

5.3.4 Pre-trends

In Panel D in Tables 5.6 and 5.7, we test for pre-trends in the fiscal variables. We use a variable that represents the damage caused by the hurricane in the period before the storm occurred. The results show that there are slightly positive effects on county expenditures and revenues. However, the trend variable is not statistically significant.

5.3.5 Fisher randomization test

To test the robustness of the results, we perform a Fisher randomization test (Fisher, 1935). We randomize hurricane damages across counties and years and re-run the baseline model with total expenditures and revenues. The 95% confidence intervals are based on repeating this procedure 1000 times and are shown in Table 5.8 with the original model coefficients. It stands out that zero is included in all 95% confidence intervals, which indicates that there is no significant effect on the fiscal variables. Further, the significant coefficients from our original model are not included in the 95% confidence interval except for the coefficient HD_{t-4} in the revenue model. Therefore, we can conclude that our results are unlikely to be driven by chance.

Table 5.8: Fisher randomization test

	Total expenditures			*Total revenues*		
	Coefficient	CI 2.5%	CI 97.5%	Coefficient	CI 2.5%	CI 97.5%
HD_t	0.019***	-0.0098	0.0099	0.017***	-0.0101	0.0098
HD_{t-1}	0.021	-0.0107	0.0108	0.020	-0.0103	0.0104
HD_{t-2}	0.009	-0.0102	0.0107	0.009	-0.0106	0.0106
HD_{t-3}	0.016***	-0.0104	0.0109	0.015***	-0.0109	0.0112
HD_{t-4}	0.018***	-0.0105	0.0106	0.010***	-0.0109	0.0109
HD_{t-5}	0.004	-0.0102	0.012	0.003	-0.0107	0.0125

Significance-codes: **p<0.05; ***p<0.01

Note: This table depicts the Fisher randomization test for total expenditures and revenues from our baseline regression. We report the original coefficients from Table 5.1 Column 2 and 5 and the 95% confidence interval from 1000 randomizations.

6 Discussion and conclusion

In this thesis, we estimate the impact of hurricanes on fiscal costs of county governments in Florida from 1993-2019. To estimate damages, we use the hurricane destruction index introduced by Strobl (2011, 2012). It takes into account local wind speeds derived from a physical wind field model and local damage potential in the form of population weights. We perform a detailed analysis of not only total county expenditures and revenues but also of the different categories and the composition.

The analysis confirms the effect of extreme events, especially hurricanes, on fiscal variables. There is a significant increase in total county expenditures which persists over several years. This finding is in line with the literature on natural disasters and their economic consequences (Miao et al., 2018, 2020; Noy et al., 2023; Ouattara & Strobl, 2013). In the year following a hurricane's impact on the county, the effect on total expenditures is the largest but remains statistically insignificant, primarily due to substantial variation. This is not only visible for total county expenditures but also for total county revenues. Including Category 2 hurricanes on the Saffir-Simpson scale renders the effect highly significant. This indicates that Category 1 hurricanes have a comparatively smaller impact on fiscal variables, diluting the effects of more damaging hurricanes in year t+1. A similar pattern is observed two years after the hurricane. The inclusion of Category 1 hurricanes continues to dilute the effect, as evidenced by the more pronounced impacts when the analysis is restricted to Category 2 hurricanes and higher. However, the overall effect remains statistically insignificant. The smaller impact on total expenditures can mainly be attributed to lower public safety expenditures. The reason for that would prove interesting for further research. In years t+3 and t+4, the impact on total expenditures is again highly significant for all categories which is similar to Miao et al. (2018). Their results show the peak in year three after the hurricane. Five years after the hurricane occurred, the effect is no longer visible in our analysis.

Generally, there is a positive effect on almost all expenditure categories. In line with the emergency management plan, public safety and physical environment costs increase to provide emergency and disaster relief, manage resources, and control floods. Besides an increase in general government services, which includes debt service payments, the other uses and non-operating expenditures increase three and four years after the hurricane. This category includes interest payments and payments to refunded bonds. The increase in both categories suggests how the costs of disaster relief and recovery are, at least in part, financed. This is in line with Jerch et al. (2023). Additional expenses can be compensated through decreases in other expenditures, increases in gross domestic product and taxable income, or other sources of funds (Deryugina, 2022). The growth in these categories results in a change in the composition of total expenditures. As these categories expand, the proportion of other categories declines. This could suggest a reduction in the provision of public goods that could have long-term fiscal implications (Deryugina, 2022). However, in absolute terms, no significant decreases were observed. Therefore, it is likely that the additional expenses were funded not by cutting other categories, but through increased revenues.

There is a significant increase in total revenues. Generally, the effect is slightly more pronounced for total expenditures than for total revenues. A likely explanation could be the increase in economic activities through post-disaster aid such as medical services, cleaning up debris, and rebuilding infrastructure which counterweights the impact of destroyed capital on revenues. As a result, the impact on revenues is softened (Horwich, 2000). We distinguish between own-source revenues and intergovernmental revenues to compare our results to the literature.

The effect on revenue categories differentiates across categories. In the period in which the hurricane occurred, there is a significant increase in intergovernmental revenues (federal and state grants) which persists for three years. This is in line with the results of Miao et al. (2023). Further, the share of intergovernmental revenues in the composition of revenue sources is also positively affected by that. This indicates that intergovernmental revenues cover the additional costs of hurricanes at least partly. Additional expenditures may be distributed across other counties and states through the federal and state governments. This argumentation is supported by the findings of Miao et al. (2023) who analyze the fiscal effects of extreme weather events at the county level. Due to the distribution of post-disaster relief costs across the counties, there is an incentive for local governments to underinvest in disaster mitigation (Cohen & Werker, 2008; Donahue & Joyce, 2001; Kapucu et al., 2010; Wildasin, 2006, 2008). This is also known as a moral hazard problem according to Coate (1995). Additionally, counties might further develop areas that are prone to hurricanes. As a result, infrastructure damages increase in the case of a hurricane event. Therefore, there should be incentives for counties to conduct pre-disaster mitigation. In other words, the allocation of fiscal responsibilities is crucial for the effective management of extreme disaster events which is in line with Miao et al. (2018).

In addition to intergovernmental revenues, own-source revenues such as tax revenues increase. This finding is in contrast to the results from Miao et al. (2023) who analyze the effect of hurricanes at the county level using the Presidential Disaster Declaration as an indicator. Other studies do not find a significant effect on own-source revenues

(Miao et al., 2018; Ouattara & Strobl, 2013). However, the increase in tax revenues in this thesis can likely be attributed to disaster recovery which leads to an increase in economic activities. Further, Deryugina (2022) states that tax revenues may increase if properties have higher values after rebuilding. Further, she explains that individuals might migrate to areas where they are more productive which could increase revenues. This explanation is supported by the results from Deryugina et al. (2018) and Groen et al. (2020) in which individual income increases after Hurricane Katarina. Further, own-revenue sources such as permits significantly increase in the the periods after the hurricane occurred. Rebuilding infrastructure and public facilities requires permits which leads to additional revenue. The additional services required for post-disaster management positively impact charges for services during the hurricane period.

In this thesis, we analyze the effect of hurricanes on fiscal costs in Florida at the county level by using a hurricane destruction index. This index accounts for potential local damages calculated with a wind field model based on hurricane track data. It is important to underline that the results are based on estimated damages in a county which is an approximation of the true unknown damages. Nevertheless, we can account for varying degrees of damage. Studying the relationship between fiscal costs of local and state governments would prove interesting for further research due to the importance of transfers for disaster relief. Besides intergovernmental revenues, there are other mechanisms for disaster aid such as insurance payments. The inclusion of these payments as a mechanism for post-disaster management could be researched in further studies.

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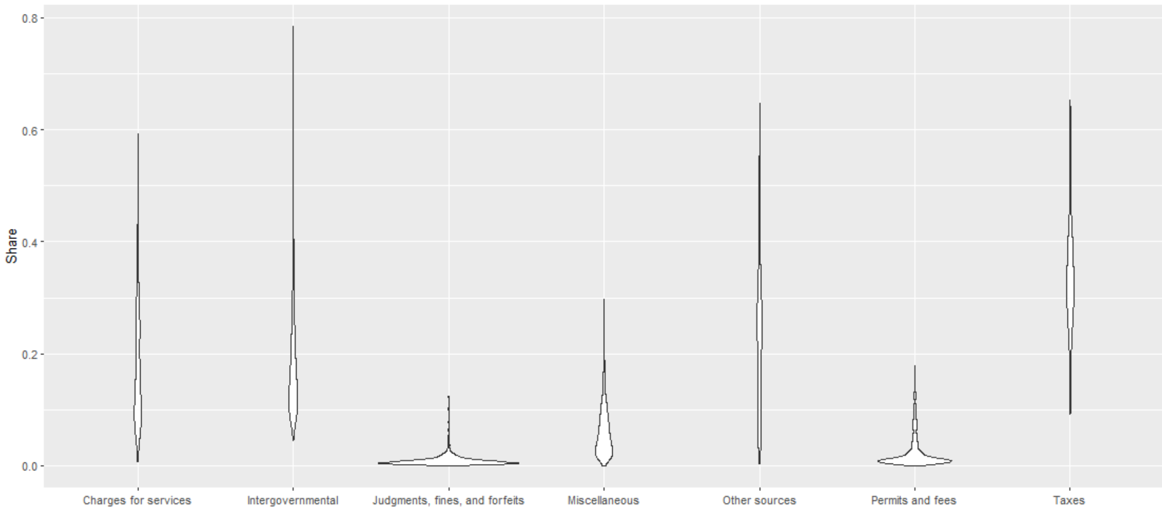
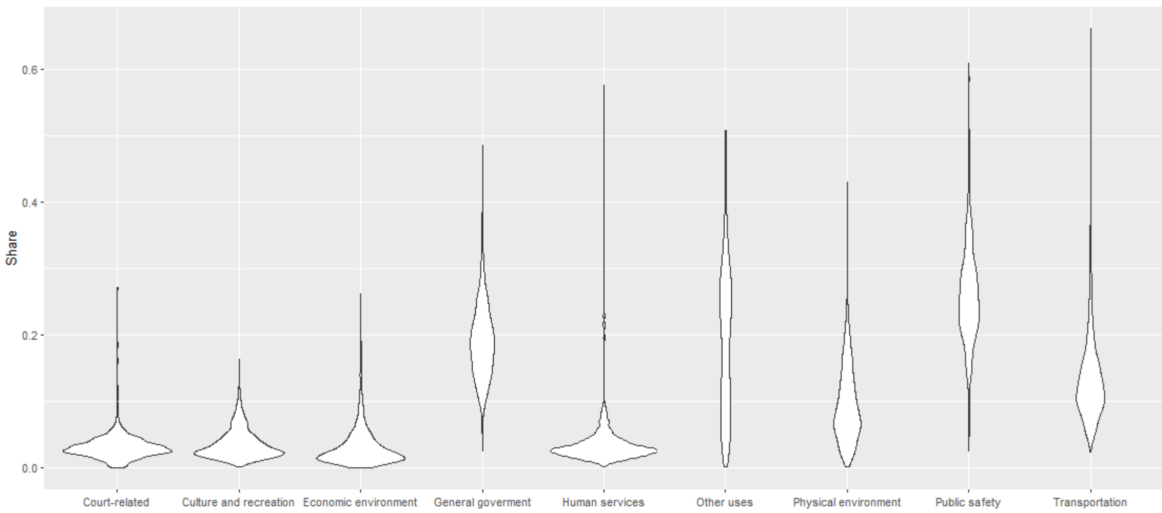
A Tables

Figure A.1: Overview of the statistical distribution of the fiscal variables depicted as the share of total county expenditures and revenues.



(a) Revenue



(b) Expenditures

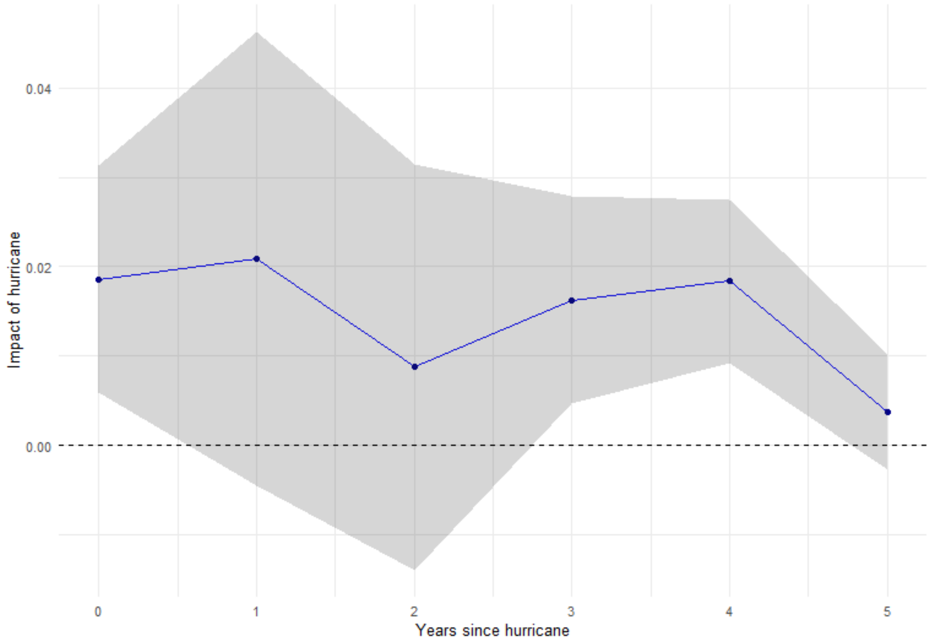
Note: The table illustrates the distribution of the counties fiscal variables from the Office of Economic and Demographic Research (2024) shown as a share of total revenues in figure A.1a and expenditures in A.1b.

Table A1: County FIPS Code Florida

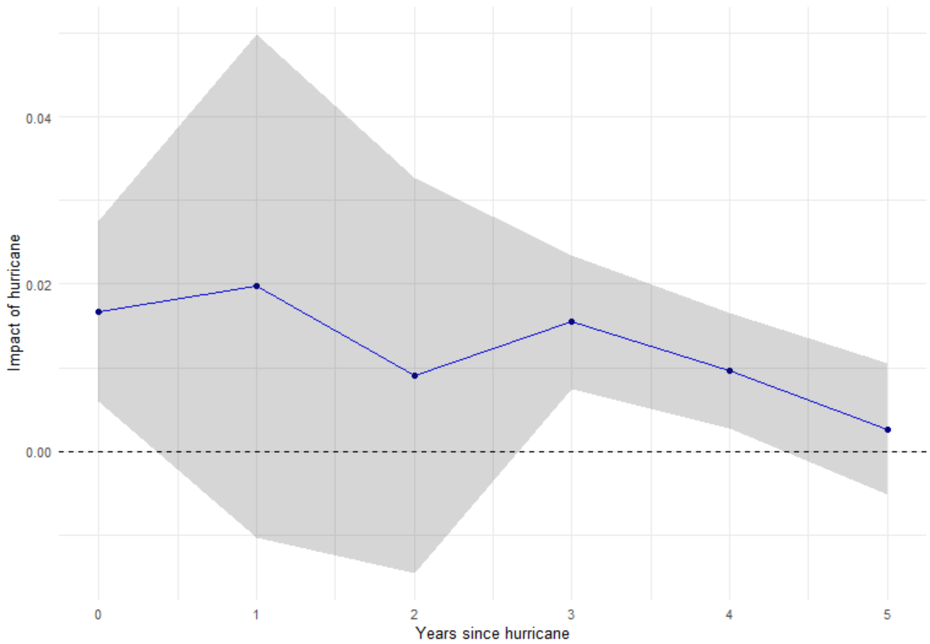
Code	County	Code	County	Code	County
001	Alachua	049	Hardee	091	Okaloosa
003	Baker	051	Hendry	093	Okeechobee
005	Bay	053	Hernando	095	Orange
007	Bradford	055	Highlands	097	Osceola
009	Brevard	057	Hillsborough	099	Palm Beach
011	Broward	059	Holmes	101	Pasco
013	Calhoun	061	Indian River	103	Pinellas
015	Charlotte	063	Jackson	105	Polk
017	Citrus	065	Jefferson	107	Putname
019	Clay	067	Lafayette	109	St Johns
021	Collier	069	Lake	111	St Lucie
023	Columbia	071	Lee	113	Santa Rosa
027	Desoto	073	Leon	115	Sarasota
029	Dixie	075	Levy	117	Seminole
031	Duval	077	Liberty	119	Sumter
033	Escambia	079	Madison	121	Suwannee
035	Flagler	081	Manatee	123	Taylor
037	Franklin	083	Marion	125	Union
039	Gadsden	085	Martin	127	Volusia
041	Gilchrist	086	Miami-Dade	129	Wakulla
043	Glades	087	Monroe	131	Walton
045	Gulf	089	Nassau	133	Washington
047	Hamilton				

Source: United States Census Bureau (2020)

Figure A.2: Comparison of hurricane impact on total expenditures and revenues



(a) Total county expenditures (in log)



(b) Total county revenues (in log)

Note: The Figure visualizes the estimated impact of hurricane destruction on total expenditures and revenues and the corresponding 95% confidence intervals from Table 5.1 Column 2 and 5.

Declaration of consent

on the basis of Article 30 of the RSL Phil.-nat. 18

Name/First Name: Mascarucci Jenny

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Study program: Climate Sciences

Bachelor ☐ Master ☑ Dissertation ☐

Title of the thesis: Assessing the Fiscal Impact of Hurricanes on Counties in Florida

Supervisor: Prof. Eric Strobl Ph.D.
Prof. Ralph Winkler Ph.D.
Ph.D. Joël Hüsler

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