Journal of Environmental Economics and Management 133 (2025) 103203

Contents lists available at ScienceDirect

Journal of Environmental Economics and Management

journal homepage: www.elsevier.com/locate/jeem

Gone with the wind? Impacts of hurricanes on college enrollment and completion☆

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ARTICLE INFO

JEL classification:
Q54
I24
J24

Keywords:
Hurricane
Natural disaster
Human capital
College enrollment
College completion

ABSTRACT

Hurricanes have significant and growing economic impacts. While the physical destruction is immediately visible, the disruptions to education and their long-term effects on human capital are often less apparent. This study examines the impact of hurricanes on U.S. higher education enrollment and completion using data from the Integrated Postsecondary Education Data System and a Differences-in-Differences Event Study approach. We find that two-year colleges experience an approximately 10 % decline in both enrollment and the number of degrees and certifications awarded within a decade following a hurricane, whereas four-year institutions exhibit no significant effects. The impact is more pronounced in institutions exposed to higher hurricane intensity and frequency, public two-year colleges, and those with a greater reliance on local student populations and higher admission rates. These effects appear to be driven by shifts in migration patterns, declines in high school graduates, and local labor market disruptions. Our findings suggest that targeted government disaster aid for community colleges could be more effective.

1. Introduction

Natural disasters, particularly hurricanes, pose significant threats to local economies and human capital development (Van Aalst, 2006; Walz et al., 2021).Climate change and ecosystem degradation, which have intensified in recent years, are expected to exacerbate these threats (Coronese et al., 2025), and a comprehensive understanding of their long-term consequences is essential for an informed policy response. While the economic impacts of hurricanes and cyclones are well-documented, with studies highlighting depressed income growth, out-migration, and disrupted housing markets (Boustan et al., 2020; Deryugina, 2017; Graff Zivin et al., 2023; Nguyen and Mitrou, 2025; Strobl, 2011), the long-term effects on higher education enrollment and completion remain relatively understudied.

Human capital, encompassing the knowledge, skills, and experiences individuals possess, is a critical driver of economic prosperity (Psacharopoulos and Patrinos, 2004). Investments in education and training are essential for building human capital, and disruptions caused by natural disasters could significantly hinder this process (Cook and Beachy, 2019; Opper et al., 2023; Özek, 2023). Research has explored how hurricanes influence human capital by examining migration patterns, student test scores, and educational

☆ We sincerely appreciate the valuable feedback from Anna Aizer, Melanie Morten, Douglas Harris, Justin Yifu Lin, Wei Long, Emily Cook, Yong Wang, Mary Olson, and participants at the Southern Economic Association 2022 Annual Conference, Chinese Economists Society 2024 Annual Conference, as well as seminars at Tulane University, Peking University, and Liaoning University. All remaining errors are solely our responsibility.

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https://doi.org/10.1016/j.jeem.2025.103203
Received 30 September 2024; Received in revised form 8 June 2025; Accepted 19 June 2025
Available online 23 June 2025

attainment across different levels (Sacerdote, 2008; Opper et al., 2023).While studies document out-migration and mixed results on test scores, evidence suggests a potential decline in college enrollment following hurricanes (Sacerdote, 2008; Opper et al., 2023). This finding warrants further investigation, particularly considering the crucial role higher education plays in upward mobility and career opportunities.

Higher education presents a distinct case compared to K-12 education. Unlike mandatory K-12 schooling, enrollment in higher education is a personal choice influenced by a complex interplay of factors, including local labor market conditions, living environment, and individual financial situations (Connor, 2001; Cullinan et al., 2013). Depressed wages and job losses post-hurricane could potentially discourage college enrollment as individuals prioritize immediate economic needs or lack the resources to pursue higher education. In addition, unlike free K-12 education, higher education could be quite expensive, with significant tuition barriers and more stringent admission requirements(Avery and Turner, 2012). Furthermore, natural disasters may affect the local economy, which in turn affects the operations of educational institutions, especially schools serving vulnerable groups and disadvantaged students. These factors render higher education particularly susceptible to disruptions caused by natural disasters. Hurricanes might strain family finances, displace students and institution, negatively impact local job markets, and influence career aspirations, potentially leading students to choose programs with diminished job prospects.

Despite the growing body of research on the economic and human capital impacts of hurricanes, a crucial gap remains in our understanding of their short-term and long-term effects on higher education enrollment and completion. Existing studies primarily focus on the immediate aftermath and single hurricane, with limited exploration of the persistent consequences that may unfold over years (Shughart, 2006; Dari-Mattiacci and Faure, 2015). This knowledge gap hinders our ability to develop effective policy responses that mitigate the long-term disruptions caused by natural disasters on educational attainment.

This study investigates the impact of hurricanes on higher education enrollment and completion in the United States from 1986 to 2019. To achieve this objective, we leverage data from the Integrated Post-secondary Education Data System (IPEDS) and employ a Differences-in-Differences Event Study (DD-ES) approach to compares the changes experienced by colleges directly affected by hurricanes to those in non-impacted areas both before and after the events. By implementing a matching scheme based on county and institution characteristics, we could minimize pre-existing differences and selection biases related to regional factors that might influence enrollment and completion. Furthermore, recognizing the distinct characteristics of two-year colleges and four-year institutions in terms of in-state student share, admission requirements, and graduate career paths, we analyze the impact on these two types of institutions separately. This allows for a more nuanced understanding of how hurricanes affect different segments of higher education.

Our findings offer several important insights into the effects of hurricanes on higher education enrollment and completion. First, we reveal the significant and long-lasting negative impacts of hurricanes on enrollment and completion, particularly for two-year colleges. Within a decade following a hurricane strike, full-time equivalent (FTE) enrollment and the number of college completions at affected two-year institutions decline by 10 %–14 %. These results remain robust across various model specifications, including alternative estimators, state-level linear time trends, and additional controls. Second, the negative effects on enrollment and completion[1] are most pronounced in areas that experience higher frequency or greater intensity of hurricanes, highlighting the cumulative and escalating nature of the disruption over time. Third, we observe significant heterogeneity in the effects across institution types and student populations. Institutions with a higher share of local students or higher admission rates, as well as public colleges, are more vulnerable to hurricane disruptions. Additionally, for four-year institutions, the negative effects are more pronounced for graduate students than for undergraduates.

Our research explores several key mechanisms through which hurricanes negatively impact higher education enrollment. First, hurricanes significantly influence migration patterns. Studies show increased net out-migration after hurricanes, both in the short- and long-term (Groen et al., 2019; Opper et al., 2023). This migration could explain a major portion of the decline in college enrollment as displaced students may face significant challenges enrolling in new institutions or experience financial burdens associated with relocation. Second, hurricanes could disrupt secondary education, leading to declines in standardized test scores and graduation (Sacerdote, 2008; Harris and Larsen, 2022; Opper et al., 2023). These disruptions could negatively impact students' college readiness and preparedness, potentially discouraging them from pursuing higher education. Finally, hurricanes may deteriorate local labor market conditions, further discouraging college enrollment (Charles et al., 2018). As job opportunities and wages decrease, particularly in specific industries, pursuing a college degree may appear less attractive, leading to a decline in enrollment in related majors. This highlights the complex interplay between local economic conditions and educational investment decisions.

This paper contributes to three strands of literature. First, it adds to the literature on the impact of hurricanes on social and economic outcomes. Extensive research has examined how hurricanes affect economic growth (Strobl, 2011), secondary education (Sacerdote, 2008; Harris and Larsen, 2022), employment and earnings (Groen et al., 2019), social insurance (Deryugina, 2017), housing markets (Graff Zivin et al., 2023), and mortality (Deryugina and Molitor, 2018). Our study complements this body of work by highlighting an understudied aspect of hurricane impacts: the consequences for human capital. To our knowledge, this is the first national study to examine the long-term impacts of hurricanes on higher education in the United States. By analyzing data encompassing all hurricanes that struck the U.S. between 1980 and 2019, our research offers a broader and more comprehensive perspective than previous studies with narrower timeframes. This extensive scope allows us to fully capture the extent of hurricane-induced disruptions to educational attainment.

[1] In this study, we use the number of degrees and certificates awarded as a measure of the number of individuals completing higher education.

Second, this paper contributes to the literature on the impact of negative economy shocks on educational attainment. While prior research has examined how economic downturns and recessions influence educational investment (Oreopoulos et al., 2012; Johnson, 2013; Jackson et al., 2021), the increasing uncertainty and adverse economic effects of extreme weather events make understanding the dynamics of natural disasters increasingly important. Our study expands this literature by demonstrating how natural disasters, particularly hurricanes, lead to declines in college enrollment and completion rates by affecting local labor market prospects and college financial constraints. In doing so, we provide new insights into the disruption of higher education investment.

Finally, this paper contributes to the broader literature on the impact of natural disasters on human capital (Cook and Beachy, 2019; Opper et al., 2023; Özek, 2023). A substantial body of research has examined how other types of disasters, such as earthquakes (Shidiqi et al., 2023) and epidemics (Jack et al., 2023; Harris et al., 2024), affect human capital accumulation and educational outcomes. Our study extends this line of inquiry by focusing on hurricanes, offering new evidence on the ways in which natural disasters shape long-term educational trajectories. Specifically, we highlight the differential vulnerability of two-year colleges compared to four-year institutions. Two-year colleges tend to serve a larger proportion of students from lower-income backgrounds and local populations, factors that likely make them more susceptible to the disruptions caused by hurricanes. This distinction provides valuable insights that could inform targeted policy interventions aimed at mitigating the negative consequences of natural disasters on access to and attainment of higher education.

The remainder of this paper is organized as follows: Section 2 provides background on hurricanes in the U.S., Section 3 describes the datasets used, Section 4 outlines the methodology, Section 5 presents the main empirical results and heterogeneous analysis, Section 6 discusses the mechanism analysis, Section 7 interprets the empirical findings and explores policy implications, and Section 8 concludes.

2. Hurricanes in the United States

The United States faces a persistent threat from hurricanes, powerful tropical cyclones that pose significant risks to life, property, and economic well-being (Strobl, 2011). These storms originate over warm ocean waters, fueled by the release of massive amounts of heat energy. As they intensify, the Saffir-Simpson Scale categorizes hurricanes into five categories based on wind speed and their potential impact.[2]

2.1. *Formation, seasonality, and geographic distribution of hurricanes*

Hurricanes form over warm ocean waters, typically in the Atlantic Ocean and Eastern Pacific Ocean, one of the most densely populated areas in the United States, where temperatures exceed 80 °F (26.7 °C). Warm water acts as the energy source, as evaporation fuels atmospheric pressure imbalances that drive hurricane development. The Coriolis effect, a large-scale atmospheric circulation pattern influenced by Earth's rotation, steers these storms and prevents them from developing near the equator.

The Atlantic hurricane season officially runs from June 1st to November 30th, with peak activity typically occurring from mid-August to late October. The average annual occurrence of North Atlantic hurricanes is around six, with a significant portion (over one-third) intensifying into major hurricanes (categories 3–5). However, hurricane activity can vary considerably from year to year. Certain factors, such as fluctuations in sea surface temperatures and El Niño-Southern Oscillation (ENSO) cycles, can influence hurricane formation and frequency. El Niño, a warming of the central and eastern equatorial Pacific Ocean, is generally associated with decreased Atlantic hurricane activity, while La Niña, the cooling phase of ENSO, is linked to increased hurricane activity. Table A1 in the Appendix provides a comprehensive list of all hurricanes that made landfall in the continental United States from 1980 to 2019. According to the table, a total of 62 North Atlantic hurricanes made landfall in the U.S. between 1980 and 2019, averaging 1.6 per year. Approximately one-third of these hurricanes were classified as major hurricanes (Category 3 or higher on the Saffir-Simpson Scale) at some point during their lifecycle.

The geographic distribution of hurricane impacts in the United States is not uniform. Coastal regions bordering the Atlantic and Gulf of Mexico are most susceptible to direct strikes, experiencing the full force of a hurricane's destructive winds, storm surge, and inland flooding. These areas are situated within the hurricane belt, where warm ocean temperatures and favorable atmospheric conditions create ideal environments for storm formation and intensification. As illustrated in Fig. 1, these areas exhibit a higher concentration of hurricane occurrences compared to inland regions.

2.2. *Economic costs of hurricanes*

Hurricanes inflict substantial economic burdens on the United States. The destruction of physical capital, including homes, businesses, and infrastructure, leads to significant financial losses for both individuals and governments. Nordhaus (2010) estimates that the average physical damage caused by each hurricane in the United States between 1970 and 2005 amounted to approximately $4.8

[2] Category 1 hurricanes, with wind speeds between 64 and 82 kt, cause minimal damage, primarily affecting buildings and leading to potential power outages. Category 2 hurricanes (83–95 kt) bring considerable damage, with stronger winds causing structural impacts. Category 3 hurricanes (96–112 kt) result in major damage, including damage to roofs and exterior walls. Category 4 hurricanes (113–136 kt) lead to catastrophic damage, downing most trees and power lines. Finally, Category 5 hurricanes, with winds exceeding 137 kt, cause catastrophic destruction, with total building failures possible.

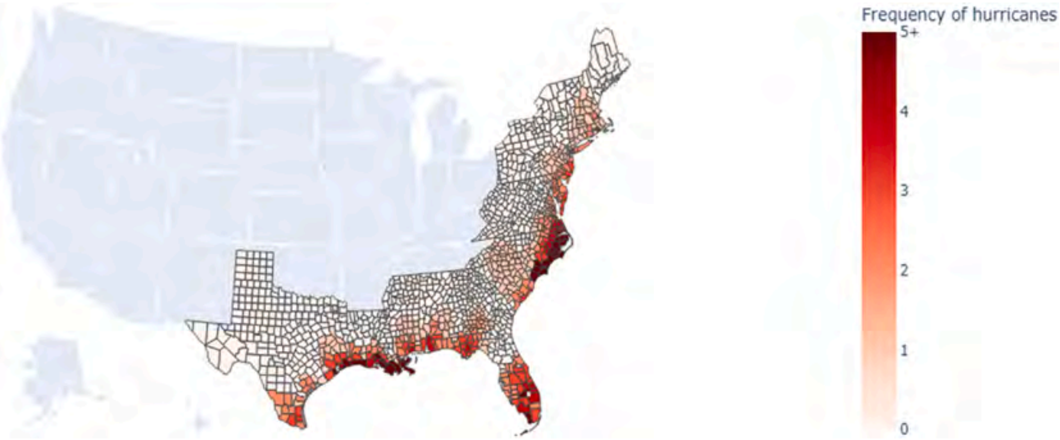

Fig. 1. Frequency of County Exposure to Hurricanes
Notes: This figure illustrates the spatial distribution of hurricane impacts across counties from 1980 to 2019, with the intensity of red indicating the number of hurricane hits. Hurricane data are sourced from the Tropical Cyclone Extended Best Track Dataset and analyzed by the authors. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

billion, or about $400 per capita between 1979 and 2002 (Deryugina, 2017). These losses primarily stem from the combined effects of strong winds and flooding associated with the storms.

Beyond direct costs, hurricanes trigger a cascade of economic consequences. Disruptions to business operations, lost wages, and decreased tourism revenue could lead to economic hardship in affected areas. Additionally, government resources are diverted towards disaster relief efforts, including search and rescue operations, debris removal, and infrastructure repairs. Deryugina (2017) highlights the substantial financial implications of hurricanes, estimating disaster-related transfers at approximately $19 billion between 1979 and 2002. Social safety net programs provide even greater financial assistance during this period, ranging from $44 billion to $65 billion. These financial transfers are crucial mechanisms to support individuals and communities in the aftermath of hurricanes, enabling recovery and rebuilding efforts. While the physical damage caused by hurricanes is immediately observable, the disruptions to education and the resulting damage to human capital are less conspicuous but equally consequential. The following empirical analysis examines these less apparent effects, providing empirical evidence on how hurricanes impact educational outcomes and human capital development.

3. Data and variables

This section details the data sources and variables employed to investigate the long-term influence of hurricanes on higher education attainment Psacharopoulos and Patrinos, 2004.

3.1. Hurricane data

Our source of hurricane data is the Tropical Cyclone Extended Best Track Dataset (EBTRK),[3] a comprehensive record of historical tropical cyclones, including hurricanes, in multiple ocean basins, managed and maintained by the National Hurricane Center (NHC) and the Hurricane Research Division (HRD), part of the National Oceanic and Atmospheric Administration (NOAA). This dataset extends and refines the earlier Hurricane Data Second Generation (HURDAT2) dataset, which focuses on tropical cyclones in the North Atlantic and Eastern Pacific regions. The EBTRK dataset provides detailed information on each storm, including storm names, geographic coordinates, maximum sustained wind speeds, minimum central pressure, and maximum wind speed radius (MWSR), recorded at 6-h intervals. We assume that the storm path follows a linear trajectory between consecutive 6-h intervals and that wind speed changes smoothly over time. Based on this assumption, we interpolate these variables to obtain 1-h intervals. The MWSR measures the spatial span of a hurricane's strongest winds. For a small number of missing MWSR values, we infer them based on the storm's maximum wind speed and central pressure. To define a county's hurricane exposure, we consider it exposed if it lies within the MWSR of a hurricane. Using this approach, 533 counties experienced hurricane exposure at least once between1980[4] and 2019, with 272 counties experiencing only one year of exposure (though some of these counties may have been affected by multiple hurricanes within the same year). Table A2 in the Appendix provides a detailed breakdown of county-level exposure to hurricanes over this period.

[3] Available from http://rammb.cira.colostate.edu/research/tropical_cyclones/tc_extended_best_track_dataset/.

[4] We collected hurricane records spanning 40 years, from 1980 to 2019. However, since college enrollment data is only available from 1986 onwards, the analysis is conducted over the sample period from 1986 to 2019.

3.2. IPEDS

The primary source of data on higher education institutions comes from Integrated Postsecondary Education Data System (IPEDS), a comprehensive administrative database collected annually by the U.S. Department of Education's National Center for Education Statistics (NCES). Mandated by the Higher Education Act of 1965, IPEDS encompasses a diverse range of institutions, including public and private universities, community colleges, for-profit institutions, and non-degree-granting institutions. The dataset covers a vast array of variables related to institutional characteristics, admissions, enrollments, tuition, finances, student retention, and degree and certificate conferrals.

In this study, we focus on two key outcome variables. The first variable of interest is the annual FTE enrollments of higher education institutions, and the second variable is college completion measured as the annual total degrees or certificates awarded by institutions.[5] To mitigate the influence of potential outliers and ensure a more normal distribution for statistical analysis, the logarithms of both these variables are employed. Additionally, we examine several institutional characteristics—including institutional level, institutional type (public, private non-profit, and private for-profit), level of study, revenue, and student demographic and characteristics—to explore potential mechanisms and assess heterogeneity in the effects.

The utilization of the IPEDS offers several key strengths for our study. First, IPEDS provides a robust dataset with essential characteristics of higher education institutions. The mandatory reporting by institutions to the U.S. Department of Education reduces reporting bias and measurement errors, enhancing data reliability. This comprehensive and reliable data is crucial for establishing a strong foundation for our analysis. Second, the data offers detailed information on enrollment and completion, disaggregated by college type, race, and level of study. This level of granularity allows us to pinpoint the groups most heavily impacted by hurricanes in terms of college level (e.g., two-year colleges v.s. four-year institutions), thereby informing targeted disaster relief policies that address the specific needs of these student groups. Last, the availability of more than 30 years of institutional data (from 1986 to 2019) enables us to investigate both the immediate and long-term effects of hurricanes on college enrollment and completion. This comprehensive time-frame provides valuable insights into the temporal dynamics at play. By examining college enrollment and completion patterns over an extended period, we could assess how hurricane impacts evolve and persist over time.

3.3. County demographic and geographic data

To address potential confounding factors, we gather detailed county-level demographic and geographic data. For demographic characteristics, we utilize information on total population, male proportion, elderly proportion (ages 65+), and young proportion (ages under 20), sourced from the Surveillance, Epidemiology, and End Results (SEER) population database, maintained by the U.S. Census Bureau. This database provides annual, county-level population data disaggregated by age and gender. For geographic characteristics, we incorporate data on land area, water area, and the number of housing units from the Gazetteer File Record Layouts (GFRL), a comprehensive resource also maintained by the U.S. Census Bureau. By integrating these variables, we aim to account for demographic and spatial factors that may influence educational outcomes and the impacts of hurricanes at the county level.

4. Identification strategy

This section outlines the econometric approach employed to isolate the causal effect of hurricanes on institutional enrollment and the total number of degrees and certificates awarded.

4.1. Propensity score matching

To accurately infer the causal effects of hurricanes, a credible counterfactual is essential. A natural approach is to use all unaffected counties as potential controls. However, this is not advisable when significant differences exist between counties that experience hurricanes and those that do not. Table 1 compares the college and county characteristics of hurricane-affected and unaffected regions. Counties that experience hurricanes tend to be more populous than non-hurricane counties, with smaller land areas, higher population densities, fewer housing units, and a lower proportion of residents under the age of 20. In hurricane-affected counties, two-year colleges tend to be more exposed to hurricanes, with an average exposure of 1.9 in our sample, compared to 1.6 for four-year institutions. To compare colleges in hurricane-affected counties with those in unaffected counties, the data also reveal several key distinctions in college characteristics: hurricane-prone regions have lower college enrollment and completion rates, a lower share of public institutions, and a higher proportion of black and Hispanic students compared to non-affected areas. All of these differences are statistically significant at the 1 % level. Given these demographic and geographic disparities, directly comparing hurricane-affected and unaffected counties could introduce bias into the estimation.

To address this issue and ensure a more comparable set of control units, we adopt a propensity score matching (PSM) approach. This method pairs counties that experienced a hurricane with those that did not, based on their pre-hurricane characteristics, reducing concerns about selection bias. We implement nearest-neighbor 1-to-1 matching at the county level using baseline county and institution characteristics as matching variables to ensure comparability between hurricane-affected and unaffected counties. Specifically,

[5] Figure A1 in the Appendix illustrates the national trends in college FTE enrollment and completion from 1986 to 2019.

Table 1
Summary statistics.

College variables	Hurricane Counties		Other Counties		P-value	
	Two-year	Four-year	Two-year	Four-year	Two-year	Four-year
FTE enrollment	1102	3392	1373	3685	<0.001	<0.001
Degree awarded	308	904	341	966	<0.001	<0.001
Public institution	0.285	0.230	0.395	0.259	<0.001	<0.001
White %	49.591	57.825	62.845	67.542	<0.001	<0.001
Black %	22.789	14.998	15.459	11.129	<0.001	<0.001
Hispanic %	19.151	12.571	11.154	6.010	<0.001	<0.001
Hurricane strikes	1.893	1.646	0.000	0.000	<0.001	<0.001
Observation	33,567	23,680	85,763	63,458		
County characteristics						
Land area	810,901		1,478,731		<0.001	
Water area	186,089		185,098		0.656	
Population (log)	13.038		12.563		<0.001	
Male proportion	0.485		0.491		<0.001	
Elderly (age>65)	0.128		0.123		<0.001	
Young (age<20)	0.234		0.245		<0.001	
# of college	5.781		3.817		<0.001	
# of housing units	344		376		<0.001	
Observation	57,247		149,221			

Notes: This table presents the summary statistics for the outcome variables and control variables in the full sample. "Hurricane counties" refers to counties that have experienced at least one hurricane, while "Other counties" refers to counties that did not experience any hurricanes during the study period. "P-value" represents the p-value from a *t*-test of the differences between the variables in "Hurricane counties" and "Other counties". Land area and water area are measured in thousand square meters. College data are derived from the IPEDS, and county data are sourced from the U.S. Census Bureau.

we match counties based on a range of key factors. At the county level, we account for geographic characteristics, such as land area and water area, as well as demographic composition, including population size, male proportion, the proportion of residents aged 65 and older, the proportion of residents aged 20 and younger, and total housing units. At the institution level, we incorporate characteristics aggregated to the county level. These include the higher education landscape, captured by the number of higher education institutions in the county and the proportion of public and private nonprofit colleges; racial and ethnic composition, measured by the percentage of college students who are white, black, and Hispanic; and enrollment and degree outcomes, measured by baseline FTE enrollment and the total number of degrees and certificates awarded.

To assess the quality of our matching procedure, Figure A2 presents the kernel density plot of propensity scores before and after matching. Prior to matching, substantial differences exist in the propensity score distributions between hurricane-affected and unaffected counties. After matching, the two distributions align closely, indicating that the matching process significantly improves comparability. Figure A3 further illustrates the effectiveness of the matching procedure by comparing differences in matching variables before and after matching. Before matching, the differences between hurricane-affected and unaffected counties range from 10 % to 80 %, whereas after matching, most these differences are reduced to within 10 %. This demonstrates that the PSM procedure successfully balances observable characteristics, ensuring that treated and control counties are more comparable. By mitigating selection bias, this matching approach strengthens the credibility of our causal estimates.

4.2. Difference-in-Difference Event Study

We leverage a Difference-in-Difference Event Study (DD-ES) approach, capitalizing on the exogenous variation introduced by hurricane occurrences within the United States between 1986 and 2019. DD-ES is particularly well-suited for this analysis as it allows us to isolate the causal impact of hurricanes by comparing the changes in enrollment and completion at institutions in hurricane-affected counties (treatment group) with the changes observed at institutions in matched non-affected counties (control group) before and after the hurricane strikes. The DD-ES approach utilizes an event study framework to capture the dynamic effects of hurricanes on educational outcomes. We estimate a regression model based on the following equation:

$$Y_{ict} = \sum_r \beta_r \left(H_c \times Event_{c,r}\right) + X'_{ict}\gamma + \gamma_i + \theta_t + \tau_r + \delta_{pt} + \epsilon_{ict} \tag{1}$$

where Y_{ict} represents the outcome variable, either the logarithm of annual FTE enrollment or the total number of degrees and certificates awarded at institution i in county c during school year t. H_c is a binary variable for hurricane exposure, which equals one if institution i is located in a county hit by a hurricane during the study period, and equals zero otherwise. $Event_{c,r}$ is a series binary variable of r-period lead or lag relative to the hurricane occurrence in county c. We define a two-year bin as one event window for Equation (1). Specifically, $r = 0$ represents the period covering the year of the hurricane strike and the following year, while $r = -1$ refers to the two-year period preceding the hurricane, which serves as the reference period in the event study analysis. For counties that never experienced a hurricane during the study period, it is set to the same value to their matched counterpart. The coefficient β_r

estimates the change in outcomes in hurricane counties relative to matched non-hurricane counties during event time *r*. X_{ict} represents a set of county- and institution-level covariates that control for regional and demographic characteristics. County-level variables include land area, water area, population size, male proportion, proportion of residents aged 65 and older, proportion of residents aged 20 and younger, and total housing units. Institution-level variables include the number of higher education institutions in the county and the proportion of public and private nonprofit colleges, and the percentages of college students who are white, black, and Hispanic. γ_i are the higher education institution fixed effects, which control for any unobserved, time-invariant differences among colleges and universities. θ_t are the year fixed effects, which accounts for national trends in across all institutions for each year. τ_r represents the event time fixed effects, which account for common trends across all institutions at each time point relative to the hurricane strike. δ_{pt} are the province-by-year fixed effects, which account for time-varying shocks that are specific to each province. Regressions are weighted by baseline college enrollment size to ensure that institutions contribute proportionally to the analysis, preventing smaller colleges from disproportionately influencing the estimates. Standard errors are clustered at the county level to account for within-county correlation in the error terms.

The event study analysis in Equation (1) has the advantage of providing estimates for each event window, both before and after the hurricane, which enables a clear depiction of the dynamic effects over time. This method is particularly suited for graphical representation, as it effectively illustrates the temporal evolution of these effects. However, given the large number of estimated coefficients across multiple event windows, the results are not ideal for presentation in tabular form. To facilitate a more concise reporting, we aggregate the event windows into broader time periods, making the presentation in tables more manageable. Specifically, we divide the 10 years following the hurricane strike into two groups: the Short-Term Effect (0–4 years), which includes the year of the hurricane and the following four years, and the Long-Term Effect (5–9 years), which covers the fifth through ninth years after the strike. As in Equation (1), the same reference period—two years prior to the hurricane strike—is used here. However, unlike Equation (1), which restricts the sample to a 20-year window (from 10 years before to 9 years after the hurricane strike), we expand the sample period to a 29-year window (from 14 years before to 14 years after the hurricane strike). This expanded window allows us to test the robustness of our results under different sample period specifications and assess whether the findings hold when the temporal scope of the analysis is extended. Following Deryugina (2017), we modified the model as follows:

$$Y_{ict} = \beta_1 H_{c,1} + \beta_2 H_{c,2} + \beta_3 H_{c,3} + \beta_4 H_{c,4} + X'_{ict}\gamma + \gamma_i + \theta_t + \tau_r + \delta_{pt} + \epsilon_{ict} \tag{2}$$

where $H_{c,1}$ represents $H_c \times Event_1(-14 \le \tau \le -3)$, $H_{c,2}$ represents $H_c \times Event_2(0 \le \tau \le 4)$, $H_{c,3}$ represents $H_c \times Event_3(5 \le \tau \le 9)$, $H_{c,4}$ represents $H_c \times Event_4(10 \le \tau \le 14)$, respectively. β_2 captures the average short-term effect of a hurricane on educational outcomes, representing the difference between treatment and control counties during the 0–4 years period, while β_3 captures the relatively long-term effect of a hurricane on educational outcomes, representing the difference between treatment and control counties during the 5–9 years period. We report both coefficients in table form to provide a comprehensive understanding of how hurricanes influence enrollment and degree attainment in both the immediate aftermath and the relatively longer term.

The DD-ES approach hinges on the critical assumption of parallel trends. This assumption posits that, absent hurricane occurrences, the treatment group (counties affected by hurricanes) and the control group (matched unaffected counties) would have exhibited similar changes in annual FTE enrollment and total completion over time. The validity of our causal estimate rests on the fulfillment of this assumption. The parallel assumption can be partially evaluated by examining the pre-hurricane trends in the estimated coefficients from the dynamic regression model. The absence of systematic differences in these coefficients prior to the hurricane strike would suggest that the parallel trends assumption holds, thereby validating our findings.

However, given that hurricanes strike in different years, our DD-ES model faces the issue of staggered treatment adoption. Specifically, when treatment occurs at different times across units, estimating causal effects in event studies can be challenging. In settings characterized by heterogeneous treatment effects, the typical two-way fixed effects regression model—including leads and lags of treatment—can yield biased estimates. This bias arises because the coefficients for leads and lags may be contaminated by effects from other periods, leading to misleading conclusions, particularly when testing for pre-treatment trends(Callaway and Sant'Anna, 2021; Goodman-Bacon, 2021; Sun and Abraham, 2021; Borusyak et al., 2024; de Chaisemartin and D'Haultfœuille, 2024). In response to this, we adopt the approach proposed by Sun and Abraham (2021), which is more robust to treatment effect heterogeneity. This method estimates the treatment effects as a weighted average, where the weights correspond to the share of cohorts that experience a given number of periods relative to the treatment. This approach improves upon traditional estimators by providing a more consistent and interpretable measure, making it particularly well-suited for our DD-ES framework. Consequently, we implement the Sun and Abraham (2021) estimator throughout our analysis to address the issue of staggered treatment adoption. Additionally, we adopt the methods proposed by Callaway and Sant'Anna (2021) and Borusyak et al. (2024) for robustness checks.

5. Empirical results

5.1. Impact of Hurricane on college enrollments and completion

This section presents the empirical findings on the impact of hurricane strikes on institutional enrollment and completion within higher education sectors. The analysis disaggregates the effects by college type (two-year colleges vs. four-year institutions). Fig. 2 visually depicts the dynamic effects of hurricanes on both college FTE enrollment and completion based on equation (1). The figure reveals a clear distinction between college types. Fig. 2(a) highlights a substantial decline in FTE enrollment at two-year colleges following a hurricane strike. This decline is about 10 % over the ten-year post-hurricane period, with the negative impact persisting

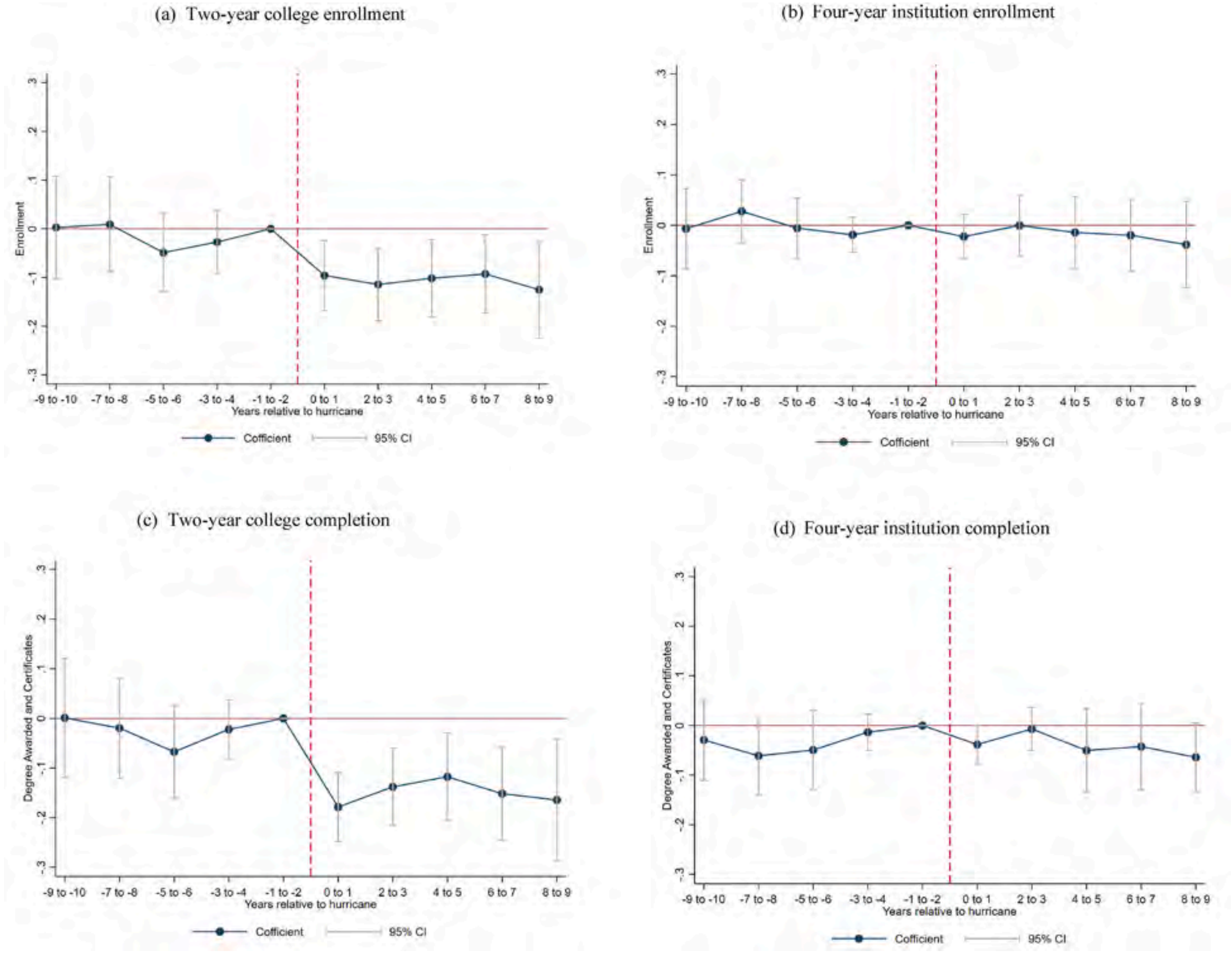

Fig. 2. The Effect of Hurricanes on College Enrollment and Completion
Notes: This figure presents the point estimates and 95 % confidence intervals of the dynamic effects of hurricanes on college enrollment and completion. Fig. 2(a) reports estimates for two-year college enrollment, Fig. 2(b) displays estimates for four-year institution enrollment, Fig. 2(c) illustrates estimates for the number of degrees and certifications awarded at two-year colleges, and Fig. 2(d) presents estimates for the number of degrees and certifications awarded at four-year institutions. All outcomes are measured in logarithmic form.

throughout. Conversely, Fig. 2(b) demonstrates no statistically significant changes in enrollment at four-year institutions in the years following a hurricane. A similar pattern emerges when examining college completion (Fig. 2(c) and (d)). There is a noticeable and persistent decline in the total number of completions at two-year colleges following a hurricane strike. In contrast, no significant changes are observed for four-year institutions. It is crucial to note that Fig. 2 also reveals no statistically significant differences in pre-hurricane trends between institutions located in hurricane-affected counties and those in non-affected counties. This finding supports the validity of the parallel assumption underlying the DD-ES strategy employed in this analysis.

To obtain more precise estimates of the short-term and long-term effects, Table 2 presents the results based on equation (2), which confirms the negative impact on FTE enrollment for two-year colleges. The average enrollment per college (approximately 1307 students) experiences a decrease of 127 (=1307 × 9.7 %) students in the short-term (0–4 year after hurricane strike) and 132(=1307 × 10.1 %) students in the relatively long-term (5–9 year after hurricane strike). There are no significant changes observed for four-year institutions. Consistent with the enrollment findings, total degree awarded for two-year colleges exhibit a decline. This translates to an average decrease of 37 (=342 × 10.9 %) degree awarded per college in the short-term and 47 (=342 × 13.7 %) in the long-term.

The empirical results demonstrate a substantial and persistent decrease in both enrollments and completion for two-year colleges following a hurricane strike. Conversely, no significant impact is observed for four-year institutions. These findings highlight the differential vulnerability of two-year colleges to hurricane disruptions and underscore the need for targeted support and intervention strategies to bolster their resilience in the aftermath of such natural disasters.

Table 2
The effects of hurricanes on college enrollment and completion.

	(1)	(2)	(3)	(4)
	Enrollment		Completion	
	Two-year	Four-year	Two-year	Four-year
0–4 years	−0.097***	−0.018	−0.109***	−0.017
	(0.031)	(0.025)	(0.039)	(0.026)
5–9 years	−0.101***	−0.022	−0.137***	−0.056
	(0.038)	(0.031)	(0.050)	(0.037)
Mean	1307	3721	342	998
R-Square	0.935	0.963	0.876	0.946
Observations	41,270	30,427	41,270	30,427
County covariates	Yes	Yes	Yes	Yes
Institution covariates	Yes	Yes	Yes	Yes
Institution FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Event time FE	Yes	Yes	Yes	Yes
State-by-year FE	Yes	Yes	Yes	Yes

Notes: This table presents the estimated effects of hurricanes on college enrollment and completion using the estimator by Sun and Abraham (2021). The dependent variables are the number of FTE enrollments and the number of degrees and certifications awarded, both expressed in logarithmic form. Columns (1) and (3) report estimates for 2-year colleges, while Columns (2) and (4) present estimates for 4-year institutions. County-level covariates include land area, water area, total population, the fraction of males, the fraction of the population under 20, the fraction of the population over 65, the number of housing units, and the number of colleges. Institution covariates include the fraction of public institutions, the fraction of private nonprofit institutions, and the percentages of white, black, and Hispanic students. Event time refers to the relative year to the hurricane strike. All regressions account for county-level covariates, institution fixed effects, year fixed effects, event time fixed effects, and state-by-year fixed effects. The sample is weighted by the logarithm of college FTE enrollment. Standard errors, clustered at the county level, are reported in parentheses. Statistical significance: *$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

5.2. Robustness checks

This section presents a series of robustness checks designed to strengthen the internal validity of our findings regarding the impact of hurricanes on higher education enrollment and completion. Specifically, we address two key concerns that could potentially bias our estimates: (1) divergent pre-existing trends, and (2) sensitivity to alternative staggered estimators.

The core assumption of our identification strategy is the exogeneity of hurricane occurrences. This assumption implies that hurricanes are not systematically influenced by factors that also affect institutional enrollment or completion, even after controlling for institution and year fixed effects. This assumption is reasonable for several reasons. Hurricanes are primarily driven by large-scale, long-term climate patterns and meteorological phenomena that are largely independent of college enrollment decisions or student outcomes. Additionally, the unpredictable nature of hurricane trajectories further supports the assumption of exogeneity, as institutions do not have prior knowledge of an impending hurricane to strategically adjust enrollment strategies. Nevertheless, we acknowledge that there may be limitations to this assumption. Over time, certain county or institutional level characteristics may exhibit trends that could correlate with hurricane occurrences.

To mitigate potential biases arising from confounding factors, we employ two robust strategies. The first is the inclusion of state-specific linear time trends,[6] which explicitly controls for pre-existing trends in enrollment and completion that may differ between hurricane-affected and non-affected counties.[7] This approach allows us to isolate the causal effect of hurricanes from underlying trends. Table A3 presents the results from models that incorporate these state-specific linear time trends. By including these trends, we permit independent trajectories in enrollment and completion for hurricane-affected and non-affected counties prior to the hurricane strike. The results remain consistent with our main findings, indicating that pre-existing trends do not significantly influence the estimated impact of hurricanes. The second approach involves using student characteristics—such as the percentage of white, black, Hispanic, and in-state students—as the outcome variable to test whether these characteristics exhibit parallel trends before the hurricane. Table A4 in the Appendix shows that these student characteristics do not exhibit systematic differential trends prior to the hurricane, suggesting that our results are not driven by selection into different types of colleges based on student demographics.

Regarding the staggered treatment issue, we utilize the Sun and Abraham (2021) estimator in our main analysis, which is robust to treatment effect heterogeneity. To further test the robustness of our findings, we also present robust staggered

[6] We construct the state-specific linear time trend by interacting state variable with the continuous year variable. This interaction term enables each state to have its own distinct trend over time, accounting for state-specific, time-varying factors that may influence outcomes, such as local economic conditions or changes in state-level policies.

[7] We opted for state-specific linear time trends rather than county-specific trends to avoid potential oversaturation. In many counties, particularly those outside urban areas, there is often only one two-year or one four-year institution. Given that our model already includes institution and year fixed effects, incorporating county-specific time trends might introduce unnecessary complexity. Using state-level trends allows us to capture broader regional shifts while maintaining a more parsimonious model.

Difference-in-Differences (DiD) estimates in Table A5 in the Appendix, using the imputation DiD estimator (Borusyak et al., 2024) and the estimator proposed by Callaway and Sant'Anna (2021). The results from both of these alternative specifications align closely with our main findings, suggesting that our results are stable across different methodological approaches.

5.3. Heterogeneous effects

This section examines the heterogeneous effects of hurricanes on enrollment and completion, focusing on factors such as exposure to hurricane frequency and scale, as well as institutional and student characteristics. Insights from this subgroup analysis provide a deeper understanding of the underlying mechanisms and offer valuable information for developing targeted mitigation strategies aimed at strengthening the resilience of higher education systems in hurricane-prone regions.

5.3.1. Hurricane frequency and intensity

Recognizing that the severity of a hurricane's impact is likely correlated with its frequency and intensity, this section examines the differential effects on enrollment and completion based on counties exposure to different hurricane frequency or categories.

Table 3 presents the heterogeneous effects of hurricane exposure, segmented by hurricane strike frequency. Panel A shows results for counties exposed to a hurricane once, while Panel B displays results for counties exposed to two or more hurricanes. In Panel A, counties affected by a single hurricane show modest and statistically insignificant effects on enrollment and completion for both two-year and four-year institutions. In Panel B, significant effects are only observed for two-year colleges, with enrollment declining by 14.2 % and completion declining by 17.5 % in the short term (0–4 years). These effects persist in the relatively long-term (5–9 years). No significant effects are found for four-year institutions. The differential impacts between counties exposed to a single hurricane versus multiple hurricanes underscore the cumulative nature of hurricane disruptions. Multiple hurricanes compound the economic and institutional strain over time, making it more difficult for affected regions to recover fully between events. The findings suggest that counties with higher exposure to frequent hurricanes face more enduring disruptions to their educational systems. The frequency of these events may serve as an indicator of longer-term, ongoing risk, shaping how students and families perceive the stability of the region. This heightened perception of risk in turn influences enrollment decisions and completion outcomes, contributing to the more significant and lasting effects observed in counties that experience multiple hurricane strikes.

Table 4 presents the heterogeneous effects of hurricanes on college enrollment and completion, segmented by hurricane categories. Consistent with previous findings, significant effects are observed only for two-year colleges. Specifically, for two-year college enrollment, the magnitude and statistical significance of the effect increase with the hurricane's category. Category 1 hurricanes in Panel A show no significant impact, while Category 2 hurricanes in Panel B result in somewhat larger and more statistically significant effects. Category 3 and higher hurricanes in Panel C exhibit similar magnitudes but have the most significant effects on enrollment. These results suggest that stronger hurricanes, likely causing more extensive disruption to local economies and educational institutions, tend to have a more pronounced impact on enrollment. However, this pattern is less evident for college completion. While Category 1 hurricanes show significant effects on two-year completion, Category 2 hurricanes lead to a larger reduction, though this effect is less statistically significant. Moreover, Category 3 and higher hurricanes do not produce significant effects on college completion. To further investigate the relationship between hurricane category and the magnitude of the effect, we designate counties exposed to Category 1 hurricanes as the control group and those exposed to hurricanes stronger than Category 1 as the treatment group. The findings for counties affected by a Category 1 hurricane versus those exposed to a Category 2 or higher hurricane are presented in Table A6 in the Appendix. The results indicate that more severe hurricanes are associated with larger declines in both enrollment and completion, although the estimates are less precise. Overall, the results provide suggestive evidence that hurricane intensity plays a role in shaping the magnitude of the educational disruptions caused by these natural disasters.

5.3.2. Student residence and admission rate

Considering that hurricanes tend to have a geographically concentrated impact, they may disproportionately affect institutions with a higher share of local students, who are more likely to be displaced or face significant challenges in continuing their education due to local infrastructure and economy damage. This section examines the differential effects on enrollment and completion based on in-state student share and admission rate.

Table 5 presents the results for institutions with high and low shares of local students. Due to data limitations arising from the lack of in-county student information, we categorize institutions based on an in-state student proportion of 75 %. The findings reveal that the negative effects on enrollment and completion are more pronounced and statistically significant for institutions with a higher proportion of in-state students. Specifically, in Panel A, institutions with an in-state student share of 75 % or more show significant declines in two-year enrollment and two-year completion ranging from 8 % to 13 %, but not for four-year institutions. These findings suggest that institutions highly dependent on local student populations are more vulnerable to the disruptions caused by hurricanes. In contrast, Panel B, which shows results for institutions with an in-state student share of less than 75 %, does not exhibit significant effects on either enrollment or completion. This further emphasizes the heightened vulnerability of institutions with a higher proportion of in-state students, which may face more severe disruptions when local students are displaced or unable to continue their studies due to hurricane impacts.

Table 6 presents the heterogeneous effects of hurricanes on college enrollment and completion, with institutions grouped based on their average admission rates over the sample period. Panel A displays the results for institutions whose average admission rate is at or above their respective type-specific median, while Panel B shows results for institutions whose average admission rate is below this median. In Panel A, the effects on two-year enrollment and completion are notably negative, ranging from 14 to 18 %. Similarly, the

Table 3
Heterogeneous effects by Hurricane frequency.

	(1)	(2)	(3)	(4)
	Enrollment		Completion	
	Two-year	Four-year	Two-year	Four-year
Panel A. Counties experienced one hurricane				
0–4 years	−0.019	0.008	−0.008	0.028
	(0.048)	(0.028)	(0.073)	(0.036)
5–9 years	−0.012	0.032	−0.132	0.048
	(0.072)	(0.034)	(0.107)	(0.051)
R-Square	0.936	0.970	0.878	0.955
Observations	15,312	11,288	15,312	11,288
Panel B. Counties experienced more than one hurricane				
0–4 years	−0.142***	0.008	−0.175***	−0.011
	(0.046)	(0.035)	(0.059)	(0.038)
5–9 years	−0.137**	0.006	−0.171**	−0.042
	(0.055)	(0.041)	(0.072)	(0.045)
R-Square	0.935	0.961	0.875	0.942
Observations	25,895	19,030	25,895	19,030
County covariates	Yes	Yes	Yes	Yes
Institution covariates	Yes	Yes	Yes	Yes
Institution FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Event time FE	Yes	Yes	Yes	Yes
State-by-year FE	Yes	Yes	Yes	Yes

Notes: This table presents the heterogeneous effects of hurricanes on college enrollment and completion, stratified by hurricane frequency, using the estimator proposed by Sun and Abraham (2021). For details on the outcome variables, control variables, fixed effects, and sample weights, please refer to the notes in Table 2. Standard errors, clustered at the county level, are reported in parentheses. Statistical significance is indicated as follows: *$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

effects being small and statistically less significant for four-year institutions. In contrast, Panel B, which examines institutions with a low admission rate, reveals more modest and statistically insignificant effects across both enrollment and completion outcomes. These results suggest that institutions with a higher admission rate, which is less selective, are more vulnerable to the disruptions caused by hurricanes, potentially due to their student populations with higher likelihood of local students. While institutions with lower admission rates, which are likely more selective, may have more robust systems to manage the disruptions caused by hurricanes or may face fewer disruptions due to having a less geographically concentrated student body.

5.3.3. *College type and level*

This section examines the heterogeneous effects of hurricanes on college enrollment and completion, focusing on variations across college types (public, private non-profit, and private for-profit) and educational levels (undergraduate and graduate). Understanding these differences is crucial for assessing how institutional characteristics influence resilience to natural disasters.

Table 7 presents the heterogeneous effects of hurricanes on college enrollment and completion, categorized by college type for two-year and four-year institutions, shows distinct patterns in how different types of institutions are affected by hurricanes. The results for enrollment indicate that public institutions are more vulnerable to hurricane disruptions than private colleges. In particular, public two-year colleges experience a significant decline in enrollment and completion. In contrast, private non-profit institutions and private for-profit institutions experience smaller, statistically insignificant changes in enrollment. Regarding degree completion, the patterns mirror those found for enrollment. Both public and private non-profit two-year colleges show significant reductions in the number of college completion, while private for-profit colleges show no significant changes in degree completion. These results suggests that institutions with higher proportions of local, low-income, and disadvantage student, such as public colleges (Scott et al., 2006), are more susceptible to disruptions caused by hurricanes, as local students may be displaced or unable to continue their education due to infrastructure damage.

Table 8 presents the heterogeneous effects of hurricanes on enrollment and completion, differentiated by undergraduate and graduate students at four-year institutions. The findings indicate that the effects on undergraduate enrollment are generally small and statistically insignificant. However, graduate enrollment at four-year colleges experiences a significant 8.7 % decline in 5–9 years after hurricane strike, highlighting that graduate students may be more affected by hurricane disruptions. In terms of four-year college completion, there is no significant effect on undergraduate completion, but graduate completion at four-year institutions shows a slight decline of 10.5 %, though this result is not statistically significant. This may be due to the greater flexibility that graduate students in four-year institutions have in their educational choices. Graduate students are more likely to defer or delay their studies, or even transition into the labor market, especially when confronted with the uncertainties and disruptions caused by hurricanes. In contrast, undergraduate programs typically exhibit greater resilience, supported by more resources and systems designed to help students recover and continue their education despite external shocks.

Table 4
Heterogeneous effects by Hurricane category.

	(1)	(2)	(3)	(4)
	Enrollment		Completion	
	Two-year	Four-year	Two-year	Four-year
Panel A. Category 1 hurricanes				
0–4 years	−0.029	0.002	−0.013	−0.019
	(0.027)	(0.029)	(0.031)	(0.033)
5–9 years	−0.023	0.013	−0.086***	−0.018
	(0.029)	(0.026)	(0.032)	(0.037)
R-Square	0.934	0.967	0.884	0.950
Observations	25,170	18,587	25,170	18,587
Panel B. Category 2 hurricanes				
0–4 years	−0.060	0.026	−0.046	0.045
	(0.073)	(0.057)	(0.118)	(0.052)
5–9 years	−0.133**	0.040	−0.165	0.039
	(0.052)	(0.048)	(0.106)	(0.060)
R-Square	0.945	0.965	0.879	0.971
Observations	5777	4311	5777	4311
Panel C. Category 3 and higher hurricanes				
0–4 years	−0.107**	−0.082	0.032	0.065
	(0.050)	(0.057)	(0.076)	(0.087)
5–9 years	−0.113**	−0.020	−0.043	0.081
	(0.053)	(0.038)	(0.069)	(0.067)
R-Square	0.928	0.955	0.857	0.939
Observations	10,141	7322	10,141	7322
County covariates	Yes	Yes	Yes	Yes
Institution covariates	Yes	Yes	Yes	Yes
Institution FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Event time FE	Yes	Yes	Yes	Yes
State-by-year FE	Yes	Yes	Yes	Yes

Notes: This table presents the heterogeneous effects of hurricanes on college enrollment and completion, stratified by hurricane scale, using the estimator proposed by Sun and Abraham (2021). For details on the outcome variables, control variables, fixed effects, and sample weights, please refer to the notes in Table 2. Standard errors, clustered at the county level, are reported in parentheses. Statistical significance is indicated as follows: *$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

6. Mechanisms

6.1. Migration

This section delves into the potential mechanisms underlying the observed decline in enrollment at two-year colleges following a hurricane strike. A plausible explanation lies in the migration patterns triggered by these natural disasters. The aftermath of Hurricane Katrina serves as a stark example, with New Orleans experiencing a significant population decline. Hurricanes can disrupt daily life, damage homes and infrastructure, and threaten lives, all of which could motivate individuals to relocate.

To examine these migration dynamics, we leverage U.S. Internal Revenue Service (IRS) data on county-to-county migration spanning 1991 to 2019. This comprehensive dataset provides insights into migration patterns by tracking address changes reported on individual income tax returns. The analysis focuses on net migration rates,[8] which account for both out-migration and in-migration relative to the county's population size. Fig. 3 visually depicts the estimated impact of a hurricane strike on net migration rates. There is no statistically significant change in net migration rates before the hurricane. However, a substantial increase is observed following the hurricane strike. Table 9 presents more precise estimates using the DD-ES approach with various specifications. Take the estimate for 0–4 years as an example for interpretation. The results indicate that net migration rates experience an outflow of approximately 3 persons per 1000 population annually following a hurricane strike. In a county with a population size equal to the sample mean (232,408), this corresponds to an estimated loss of around 697 ($=232{,}408 \div 1000 \times 3$) people due to out-migration. Assuming that individuals aged 18–24 constitute about 10 % of the population, this translates to an estimated loss of 70 ($=697 \times 10\,\%$) college enrollments, including a loss of 18 ($=70 \div 4$) completions, assuming one-fourth of the enrollments would graduate in the year of enrollment. This accounts for approximately 55 % ($=70 \div (1307 \times 9.7\,\%)$) of the enrollment decline and 48 % ($=18 \div (342 \times 10.9\,\%)$) of the completion decline reported in Table 2. However, we acknowledge that not all college students who migrate out will necessarily transfer or drop out. Some students may relocate to nearby counties and continue their enrollment and completion at their

[8] The net migration rate is defined as the difference between the number of immigrants (people moving into an area) and the number of emigrants (people leaving an area) per 1000 people.

Table 5
Heterogeneous effects by in-state student share.

	(1)	(2)	(3)	(4)
	Enrollment		Completion	
	Two-year	Four-year	Two-year	Four-year
Panel A. In-state student ≥ 75 %				
0–4 years	−0.102***	−0.019	−0.121***	0.001
	(0.032)	(0.028)	(0.041)	(0.030)
5–9 years	−0.083**	−0.033	−0.131***	−0.056
	(0.040)	(0.035)	(0.050)	(0.041)
R-Square	0.940	0.969	0.879	0.946
Observations	36,379	16,003	36,379	16,003
Panel B. In-state student<75 %				
0–4 years	0.020	−0.018	−0.008	−0.029
	(0.118)	(0.033)	(0.126)	(0.041)
5–9 years	−0.058	−0.007	−0.232	−0.074
	(0.130)	(0.057)	(0.150)	(0.057)
R-Square	0.919	0.964	0.897	0.956
Observations	3990	14,025	3990	14,025
County covariates	Yes	Yes	Yes	Yes
Institution covariates	Yes	Yes	Yes	Yes
Institution FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Event time FE	Yes	Yes	Yes	Yes
State-by-year FE	Yes	Yes	Yes	Yes

Notes: This table presents the heterogeneous effects of hurricanes on college enrollment and completion, stratified by in-state student share, using the estimator proposed by Sun and Abraham (2021). For details on the outcome variables, control variables, fixed effects, and sample weights, please refer to the notes in Table 2. Standard errors, clustered at the county level, are reported in parentheses. Statistical significance is indicated as follows: *p < 0.10; **p < 0.05; ***p < 0.01.

Table 6
Heterogeneous effects by admission rate.

	(1)	(2)	(3)	(4)
	Enrollment		Completion	
	Two-year	Four-year	Two-year	Four-year
Panel A. Admission rate ≥ Median				
0–4 years	−0.184**	−0.013	−0.008	−0.017
	(0.071)	(0.030)	(0.055)	(0.040)
5–9 years	−0.158**	−0.060	−0.138*	−0.104*
	(0.077)	(0.042)	(0.074)	(0.055)
R-Square	0.855	0.964	0.825	0.950
Observations	6851	11,411	6851	11,411
Panel B. Admission rate < Median				
0–4 years	−0.041	−0.009	−0.091	−0.006
	(0.082)	(0.031)	(0.108)	(0.039)
5–9 years	−0.076	−0.017	−0.043	−0.040
	(0.100)	(0.044)	(0.159)	(0.051)
R-Square	0.839	0.969	0.823	0.955
Observations	6301	10,750	6301	10,750
County covariates	Yes	Yes	Yes	Yes
Institution covariates	Yes	Yes	Yes	Yes
Institution FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Event time FE	Yes	Yes	Yes	Yes
State-by-year FE	Yes	Yes	Yes	Yes

Notes: This table presents the heterogeneous effects of hurricanes on college enrollment and completion, stratified by admission rate, using the estimator proposed by Sun and Abraham (2021). The sample is stratified by the median of average institutional admission rates, calculated for each institution over the sample period using its available annual data. This median of averages serves as the cutoff: 77 % for two-year colleges and 67 % for four-year colleges, applied separately. Institutions with consistently missing admission rate data are excluded from this analysis. For details on the outcome variables, control variables, fixed effects, and sample weights, please refer to the notes in Table 2. Standard errors, clustered at the county level, are reported in parentheses. Statistical significance is indicated as follows: *p < 0.10; **p < 0.05; ***p < 0.01.

Table 7
Heterogeneity effects by college type.

	(1)	(2)	(3)	(4)	(5)	(6)
	Public		Private non- profit		Private for profit	
	Two-year	Four-year	Two-year	Four-year	Two-year	Four-year
Panel A. Enrollment						
0–4 years	−0.086**	−0.028	−0.055	−0.042	−0.078	0.160
	(0.037)	(0.020)	(0.091)	(0.030)	(0.048)	(0.120)
5–9 years	−0.057*	−0.057	−0.203	−0.041	−0.098	0.240
	(0.034)	(0.030)	(0.130)	(0.040)	(0.077)	(0.162)
R-Square	0.983	0.964	0.870	0.964	0.820	0.833
Observations	12,467	7153	3953	18,827	24,377	4144
Panel B. Completion						
0–4 years	−0.196***	−0.011	−0.258**	−0.040	0.047	0.095
	(0.051)	(0.027)	(0.122)	(0.038)	(0.062)	(0.113)
5–9 years	−0.184***	−0.038	−0.353*	−0.069	0.075	−0.071
	(0.060)	(0.037)	(0.196)	(0.056)	(0.089)	(0.133)
R-Square	0.906	0.976	0.844	0.948	0.800	0.768
Observations	12,467	7153	3953	18,827	24,377	4144
County covariates	Yes	Yes	Yes	Yes	Yes	Yes
Institution covariates	Yes	Yes	Yes	Yes	Yes	Yes
Institution FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Event time FE	Yes	Yes	Yes	Yes	Yes	Yes
State-by-year FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table presents the heterogeneous effects of hurricanes on college enrollment and completion, stratified by college type (public, private, and profit), using the estimator proposed by Sun and Abraham (2021). For details on the outcome variables, control variables, fixed effects, and sample weights, please refer to the notes in Table 2. Standard errors, clustered at the county level, are reported in parentheses. Statistical significance is indicated as follows: *p < 0.10; **p < 0.05; ***p < 0.01.

Table 8
Heterogeneity effects for four-year colleges by degree level.

	(1)	(2)	(3)	(4)
	Enrollment		Completion	
	Undergraduate	Graduate	Undergraduate	Graduate
0–4 years	0.001	−0.034	0.010	0.013
	(0.041)	(0.029)	(0.018)	(0.041)
5–9 years	−0.015	−0.087**	−0.006	−0.105
	(0.056)	(0.037)	(0.028)	(0.064)
R-Square	0.910	0.939	0.915	0.920
Observations	21,619	26,191	21,667	20,424
County covariates	Yes	Yes	Yes	Yes
Institution covariates	Yes	Yes	Yes	Yes
Institution FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Event time FE	Yes	Yes	Yes	Yes
State-by-year FE	Yes	Yes	Yes	Yes

Notes: This table presents the heterogeneous effects of hurricanes on college enrollment and completion, stratified by degree level (undergraduate and graduate), using the estimator proposed by Sun and Abraham (2021). For details on the outcome variables, control variables, fixed effects, and sample weights, please refer to the notes in Table 2. Standard errors, clustered at the county level, are reported in parentheses. Statistical significance is indicated as follows: *p < 0.10; **p < 0.05; ***p < 0.01.

original institution. As such, our analysis of out-migration may overestimate its explanatory power regarding the impact of hurricanes on higher education. To address this, we conducted an additional robustness check by including both migration-in and migration-out as control variables and re-estimating the main results. As shown in Table A7, the effect size drops to 7.0 % for enrollment and 5.2 % for completion, but remains statistically significant. This suggests that controlling for migration accounts for 28 % (=(9.7 %–7.0 %)÷9.7 %) of the enrollment decline and 53 % (=(10.9 %–5.2 %)÷10.9 %) of the completion decline. These findings suggest that while migration plays a role, other factors also contribute to the observed declines.

Further exploring potential demographic shifts, we examined the impact of hurricanes on the proportion of the county population aged 20 and less (see Figure A4). Our estimates suggest an immediate decline in this age cohort post-hurricane, with a cumulative reduction of approximately 4 % over a ten-year period. This reduction in the young adult population provides a plausible contributing factor to the observed declines in college enrollment, although we note that these population figures are based on intercensal estimates

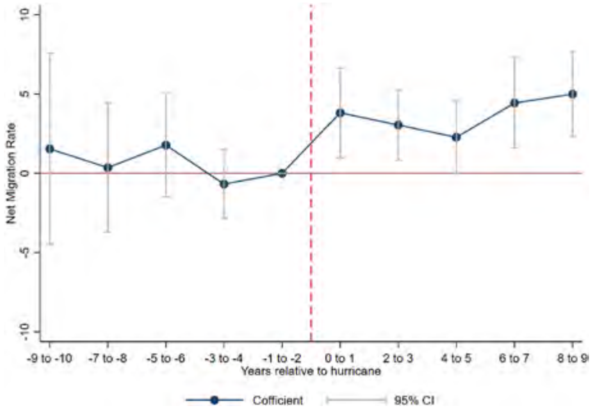

Fig. 3. The Effect of Hurricanes on County Net Migration Rate
Notes: This figure illustrates the point estimates and 95 % confidence intervals of the dynamic effects of hurricanes on county net migration rates. The net migration rate is defined as the difference between the number of immigrants (people moving into an area) and the number of emigrants (people leaving an area) per 1000 people.

Table 9
The effects of hurricanes on net migration rate.

	(1)	(2)	(3)
	Baseline	Population weight	Linear trend
0–4 years	3.037***	3.030***	3.315***
	(1.122)	(1.098)	(1.194)
5–9 years	2.544*	2.556*	1.839
	(1.445)	(1.421)	(2.158)
Population Mean	232,408	232,408	232,408
R-Square	0.675	0.679	0.705
Observations	6798	6798	6798
County linear time trends	No	No	Yes
County covariates	Yes	Yes	Yes
Institution covariates	Yes	Yes	Yes
County FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Event time FE	Yes	Yes	Yes
State-by-year FE	Yes	Yes	Yes

Notes: This table presents the estimated effects of hurricanes on net migration rate, using the estimator by Sun and Abraham (2021). The net migration rate is defined as the difference between the number of immigrants (people moving into an area) and the number of emigrants (people leaving an area) per 1000 people. Column (1) reports the baseline regression without sample weights, Column (2) applies weights based on county population, and Column (3) includes county-specific linear time trends. For details on the control variables and fixed effects, please refer to the notes in Table 2. Standard errors, clustered at the county level, are reported in parentheses. Statistical significance is indicated as follows: *p < 0.10; **p < 0.05; ***p < 0.01.

(SEER Program data).

6.2. High school graduation

The negative impact of natural disasters on college enrollment can be traced back to earlier educational stages. Numerous studies have documented the adverse effects of natural disasters on pre-K12 education (Weems et al., 2010; Archibong and Annan, 2017; David et al., 2018; Morrill and Westall, 2023; Opper et al., 2023). These impacts include the destruction of critical infrastructure such as roads, disruptions in transportation, and closures of educational institutions, leading to prolonged absences from school (Jacoby and Skoufias, 1997).In consequence, this section explores a potential mechanism by which hurricanes adversely impact higher education: the consequential loss in the number of high school enrollment and graduate, employing data on the number of high school enrollment (grade 9–12) and number of graduates from public schools between 1991 and 2019, obtained from the U.S. Department of Education's Common Core of Data (CCD). Table 10 presents the findings on how hurricanes affect the number of high school enrollment and graduation, following a hurricane strike. To isolate the net effect of hurricanes on the number of high school graduates while considering migration, the analysis incorporates controls for both out-migration and in-migration rates.

The results in Table 10 reveal that hurricanes exert a negative impact on high school enrollment and graduation, with these effects being particularly pronounced in the longer term. Fig. 4 illustrates the dynamic trend of these effects, showing a modest decline of 2 %

Table 10
The effects of hurricanes on High school enrollment and graduation.

	(1)	(2)	(3)	(4)
	Enrollment		Graduation	
0–4 years	−0.022***	−0.025***	−0.020	−0.024
	(0.013)	(0.012)	(0.016)	(0.015)
5–9 years	−0.057***	−0.059***	−0.049***	−0.052***
	(0.012)	(0.011)	(0.015)	(0.014)
Mean	2049	2049	409	409
R-Square	0.981	0.931	0.946	0.957
Observations	39,030	39,030	39,030	39,030
District covariates	No	Yes	No	Yes
In- and out-migration	Yes	Yes	Yes	Yes
County covariates	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Event time FE	Yes	Yes	Yes	Yes
State-by-year FE	Yes	Yes	Yes	Yes

Notes: This table presents the estimated effects of hurricanes on the logarithmic form of high school enrollment and graduation, using the estimator by Sun and Abraham (2021). District-level covariates include the percentage of white, black, and Hispanic students, the percentage of special education students, student-teacher ratio, poverty rate, and the proportion of the student-age population. High school enrollment is defined as the total enrollment from grades 9 to 12. Regressions are weighted by county population. For details on the county covariates and fixed effects, please refer to the notes in Table 2. Standard errors, clustered at the county level, are reported in parentheses. Statistical significance is indicated as follows: *p < 0.10; **p < 0.05; ***p < 0.01.

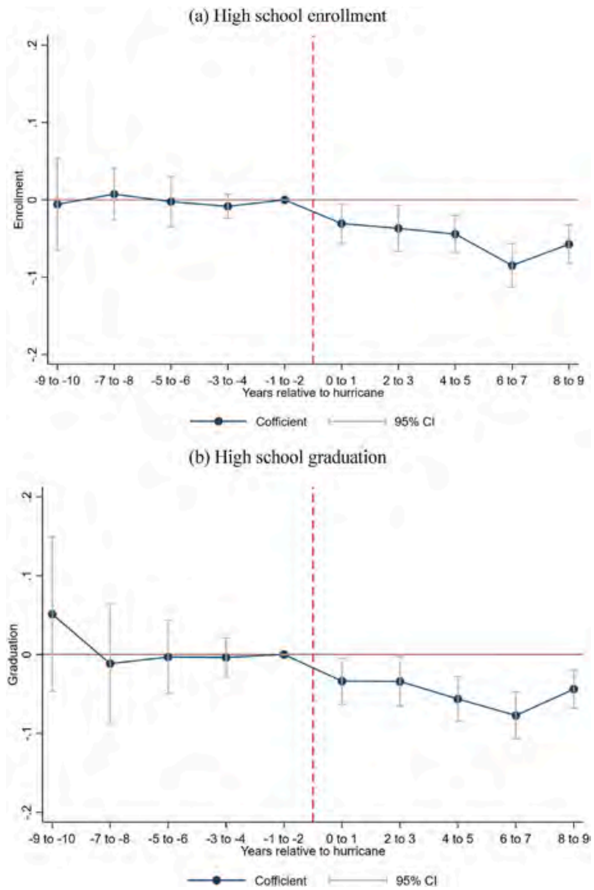

Fig. 4. The Effect of Hurricanes on High School Enrollment and Graduation
Notes: This figure illustrates the point estimates and 95 % confidence intervals of the dynamic effects of hurricanes on high school enrollment and graduation. In this analysis, enrollment represents the total number of students in grades 9 through 12, while graduation represents the total number of graduates. All outcomes are measured in logarithmic form.

in the first four years following a hurricane strike, which intensifies to 5 % in the 5–10 years thereafter. In addition, we examine the effect of hurricanes on high school graduation rates, and the results, presented in Figure A5, indicate no statistically significant impact.[9] To further explore how the decline in high school enrollment and graduation translates into differential effects on two-year and four-year institutions, we analyze IPDES data on freshman enrollment among high school graduates from the previous 12 months. Figure A6 presents the results, suggesting that the decline in high school graduates primarily affects freshman enrollment at two-year colleges, while the impact on four-year colleges is less pronounced and less precisely estimated. The findings of this section demonstrate that hurricanes can lower the number of high school graduates, thereby reducing the potential pool of students prepared to transition to higher education. This disruption to the educational pipeline is another key mechanism contributing to the decline in college enrollment observed after hurricanes, particularly for two-year institutions that often rely heavily on local student populations.

6.3. Labor market perspective

Hurricanes represent a significant threat not only to physical infrastructure but also to local economies, disrupting businesses and affecting overall labor market conditions (Deryugina, 2017). The health of the local labor market plays a pivotal role in college enrollment, especially for students considering two-year institutions, as the earnings of their graduates are closely tied to local economic trends (Oreopoulos et al., 2012). The anticipated return on investment from a college degree is a crucial factor in students' decisions to pursue higher education (Beffy et al., 2012; Wiswall and Zafar, 2015). Therefore, shifts in the labor market following hurricanes could contribute to declines in both enrollment and completion rates. Also, the impact of hurricanes on the labor market may not be uniform across all sectors. These sectoral shifts can influence the perceived benefits of attending college. If the wage gap between college-educated workers and those without a degree narrows in specific sectors due to these labor market dynamics, students may be less inclined to enroll in higher education programs, especially those not aligned with in-demand sectors.

To better understand how hurricanes affect local labor markets, we utilized data from the Bureau of Labor Statistics' Quarterly Census of Wages and Employment (QCEW). Fig. 5 highlights the dynamic changes in employment rates and average wages following a hurricane, with a pronounced long-term decrease, particularly in the 5–9 years after the event. Previous studies demonstrate that Hurricane Katrina led to a surge in demand for the construction and manufacturing industries (Hallegatte et al., 2007), resulting in increased employment and wages in these sectors, while industries such as healthcare, leisure, and accommodation experienced declines (Groen et al., 2019). Building on this evidence, we further analyze the heterogeneous effects across different sectors by examining the point estimates, as presented in Table 11. Negative impacts on employment and average wages were observed in sectors such as health and arts. For sectors are more sensitive for economic shock and uncertainty(Tanaka et al., 2019), including finance, management, and information, we also find declines of employment and average wages. Finance, management, and information sectors reflect broader shifts in the local job market, as businesses adjust to the changing economic conditions, and there is an increased demand for financial services and management expertise to aid in disaster recovery and restructuring. However, no significant changes were noted in the building and manufacturing sectors, reflecting the demand for disaster recovery perhaps offsetting the shock caused by the hurricane. These sector-specific labor market disruptions have important implications for college enrollment decisions. Local labor market conditions within particular industries could significantly influence student choices regarding college majors, as they directly impact future earnings potential (Beffy et al., 2012; Wiswall and Zafar, 2015). Our findings show a decline in employment in sectors like health, arts, finance, management, and information, which may lower the perceived returns to degrees in these fields. Consequently, students may be deterred from pursuing or completing degrees in sectors with diminished future earnings prospects.

7. Interpretation and policy implications

This section interprets our empirical findings, beginning with an exploration of the sources of the observed effects. We then discuss the effect size and compare our results with related studies, concluding with a consideration of the policy implications.

7.1. Interpretation

To better understand the sources of the effects, we distinguish between freshman enrollment and returning students.[10] As shown in Fig. 6, for two-year colleges, both freshman enrollments and returning students decline following a hurricane strike. Returning students experience an immediate decline that persists over the long term, while freshman enrollment begins to decline only two years after the hurricane and continues to trend downward. The magnitude of the decline is more pronounced among returning students, suggesting that disruptions to students continuing their education are a primary driver of the overall reduction in enrollment.

[9] It is important to note that the interpretation of graduation rate trends should be approached with caution, as the National Center for Education Statistics (NCES) changed its method of reporting graduation rates from the Averaged Freshman Graduation Rate (AFGR) to the Adjusted Cohort Graduation Rate (ACGR) starting in 2010. The ACGR provides a more accurate measure of graduation rates by tracking a cohort of first-time 9th graders and adjusting for students who transfer in or out. In contrast, the AFGR estimates graduation rates using aggregate enrollment data and compares the size of the incoming freshman class to the number of high school diplomas awarded four years later.

[10] Freshman enrollment data in IPEDS is available only for the years 1991, 1993, 1995, 1997, and 1999–2019. The enrollment of returning students is estimated as the difference between total enrollment and freshman enrollment.

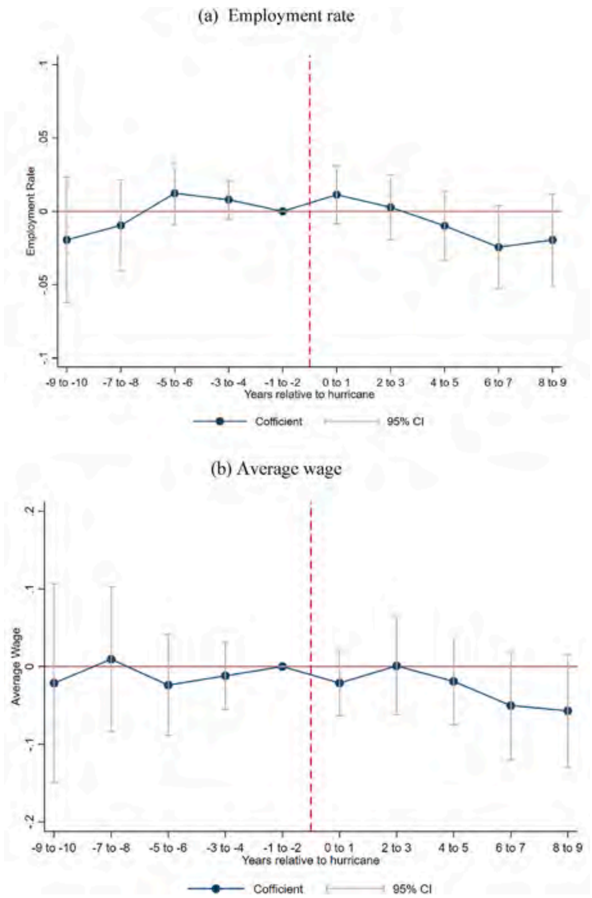

Fig. 5. The Effects of Hurricanes on Labor Market Outcomes
Notes: This figure illustrates the point estimates and 95 % confidence intervals of the dynamic effects of hurricanes on county employment rates and average wages. The employment rate is defined as the number of employees relative to the adult population. The average wage is calculated as the total wage divided by the number of employees.

Regarding college completion, we examine another key measure: graduation rates.[11] As shown in Fig. 7, for two-year colleges, we observe a significant immediate decline in the graduation rate in the year of the hurricane strike and the following year, likely driven by the reduction in returning student enrollment. This decline in graduation rates is no longer significant in subsequent years, possibly due to the combined effects of both lower enrollment and lower completion rates. No significant decline in either enrollment or graduation rates is observed for four-year colleges, suggesting that the impact of hurricanes on both enrollment and completion is more pronounced at the two-year college level.

Existing research on the impact of natural disasters on school enrollment and graduation generally yields similar conclusions, but most studies focus on primary and secondary education. For example, studies on the impact of Hurricane Matthew (Cook and Beachy, 2019) and Hurricane Maria (Ozek, 2020) on high school enrollment found that approximately 35 % of students did not return to school. Similarly, a study of the 2006 earthquake in Indonesia revealed that the earthquake reduced the school year by about 0.74 years and lowered the compulsory school completion rate by 10 %–11 % (Shidiqi et al., 2023). Jensen (2000) found that in areas of the Ivory Coast that experienced extreme weather shocks between 1986 and 1987, enrollment rates declined by about 20 %, compared to areas not affected by the shocks. Few studies have examined the impact of natural disasters on higher education. Harris et al. (2024) report that enrollment in two-year public colleges decreased by 10 % from 2021 compared to pre-COVID levels, while four-year public enrollment declined by approximately 1 %. Opper et al. (2023) find that disasters causing per capita losses between $100 and $500 lead to a 2 %–3 % reduction in higher education enrollment. In our study, we observe a 10 % decline in enrollment at two-year colleges. Given that the average per capita loss from hurricanes is approximately $400 (Deryugina, 2017) and that two-year colleges represent about one-fourth of all U.S. students (Figure A1), the national average enrollment effect could be around 2.5 %. When accounting for migration, the reduction in two-year college enrollment is closer to 7 % (Table A7), which results in an estimated national average effect of 1.8 %, closely aligning with the findings of previous studies.

[11] The graduation rate is measured as the IPEDS 150 percent of normal time graduation rate, which is available for 1996–2017.

Table 11
The effects of hurricanes on labor market outcomes by industry.

	(1)	(2)	(3)	(4)
	Employment	Wage	Employment	Wage
	All industries		Health and art	
0–4 years	−0.001	−0.035*	−0.001	−0.065**
	(0.010)	(0.020)	(0.010)	(0.031)
5–9 years	−0.021*	−0.066**	−0.006**	−0.126**
	(0.013)	(0.033)	(0.003)	(0.056)
Mean	0.806	3053	0.075	3389
R-Square	0.941	0.932	0.918	0.856
Observations	20,940	20,940	20,940	20,940
	Building and manufacture		Finance, management & information	
0–4 years	0.001	0.055	−0.002	−0.005
	(0.002)	(0.024)	(0.008)	(0.033)
5–9 years	0.002	0.070	−0.010**	−0.011
	(0.003)	(0.031)	(0.004)	(0.050)
Mean	0.123	4041	0.107	3726
R-Square	0.956	0.777	0.918	0.870
Observations	21,984	21,984	21,808	21,808
County covariates	Yes	Yes	Yes	Yes
Institution covariates	Yes	Yes	Yes	Yes
Institution FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Event time FE	Yes	Yes	Yes	Yes
State-by-year FE	Yes	Yes	Yes	Yes

Notes: This table presents the estimated effects of hurricanes on labor market outcomes, stratified by industry. The dependent variables include employment rates and average wages across various sectors. The results are based on the estimator by Sun and Abraham (2021). The employment rate is defined as the number of employees relative to the adult population. The average wage is calculated as the total wage divided by the number of employees. Regressions are weighted by county population. For details on the county covariates and fixed effects, please refer to the notes in Table 2. Standard errors, clustered at the county level, are reported in parentheses. Statistical significance is indicated as follows: *$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

7.2. Policy implications

Our findings underscore the significant economic consequences of hurricanes on higher education, particularly in terms of enrollment and degree completion. The disruptions caused by hurricanes affect both the financial stability and operational capacity of institutions, with two-year colleges, which are more reliant on local student populations, being especially vulnerable. Changes in revenue patterns observed in response to these disruptions provide valuable insights for policymakers. Table A8 presents results of financial impact from hurricane strike. Specifically, the results suggest a significant reduction in total state and local appropriations[12] for two-year colleges—although this reduction is not statistically significant at the per-student level. This decline may partially reflect broader fiscal constraints faced by local governments following a disaster, and is partially a consequence of the decline in enrollment.[13] This situation creates a negative feedback loop that impedes institutional recovery and long-term sustainability. In contrast, four-year colleges tend to experience an increase in federal appropriations per student, which may help buffer the financial strain caused by hurricanes. This highlights the important role that government funding plays in stabilizing institutions and supporting their resilience during such crises. No meaningful patterns were observed for revenues from tuition fees across both types of institutions.

Given these financial impacts, our results suggest that increasing government funding is crucial for mitigating the long-term effects of hurricanes on college enrollment and degree completion. Deming and Walters (2018) have demonstrated that increased educational spending can significantly boost college enrollment and degree attainment, with estimates indicating that doubling college expenditures leads to a 30.0 % increase in enrollment and a 79.9 % rise in the number of degrees awarded in the short term. Our findings indicate that hurricanes reduce enrollment and degree attainment by 9.7 % and 10.9 %, respectively, in the short run. Given that the average total spending per institution in 2019 was $1.71 million, we estimate that, to fully offset the short-term declines in enrollment and degree completion through increased funding alone, an additional investment of approximately $0.23 million to $0.55 million per institution would be required.[14]

These findings carry significant implications for disaster relief policies. Our research suggests that targeted support for two-year colleges, especially those in hurricane-prone areas, could be particularly effective in addressing their greater vulnerability to

[12] Local appropriation refers to funds allocated by local governments (e.g., county or municipal governments) to support the operation and infrastructure of public institutions such as community colleges.

[13] A corollary belief is that if enrollments are maintained, state appropriations will also be maintained, and if enrollments decline, state appropriations will decline proportionally (Leslie and Ramey, 1986).

[14] The detailed calculations for these estimates are as follows: $0.23 = 1.71 \times (10.9\ \% \div 79.9\ \%)$, $0.55 = 1.71 \times (9.7\ \% \div 30.0\ \%)$.

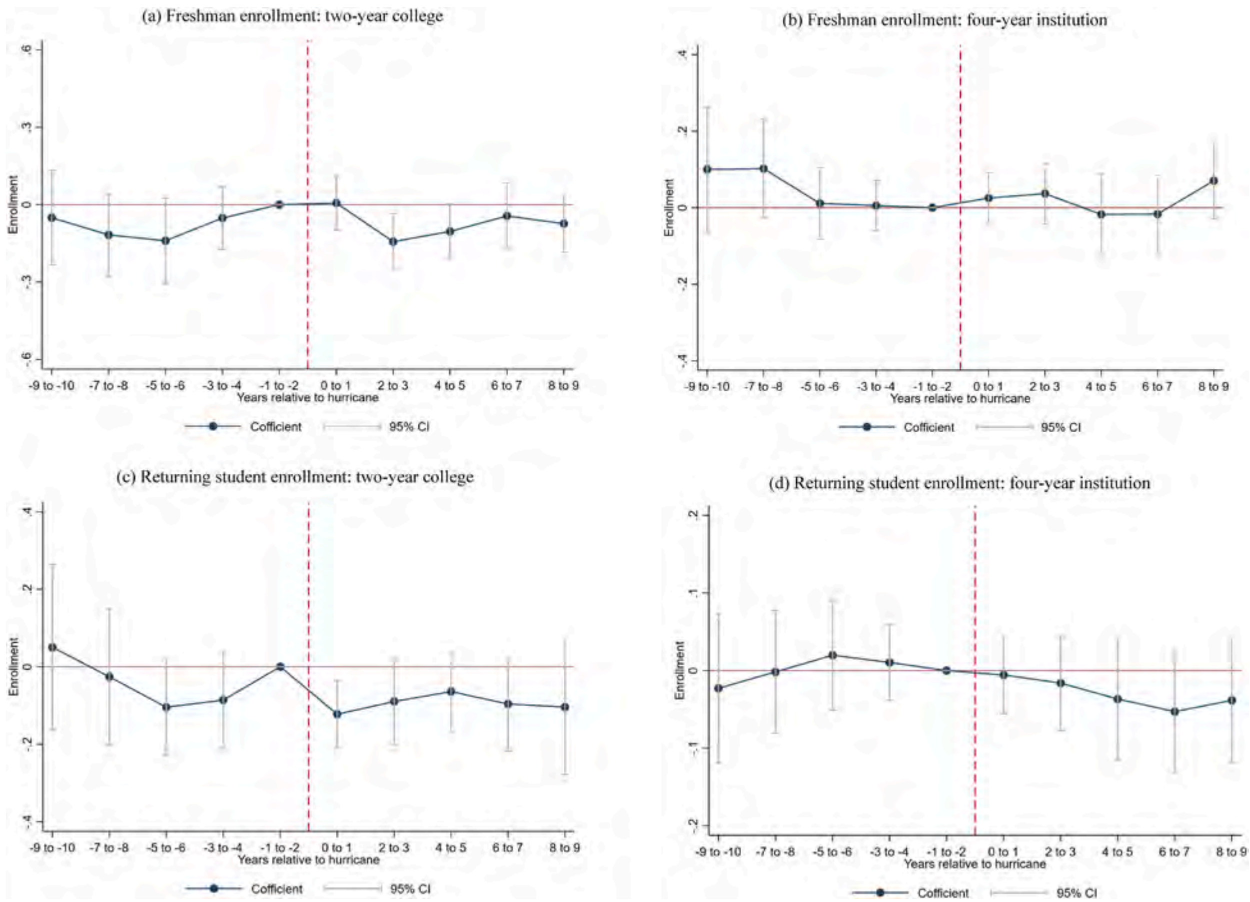

Fig. 6. The Effects of Hurricanes on Freshman Enrollment and Returning Student Enrollment
Notes: This figure illustrates the point estimates and 95 % confidence intervals of the dynamic effects of hurricanes on freshman enrollment and returning student enrollment. Fig. 6(a) and (b) show estimates for freshman enrollment, while Fig. 6(c) and (d) display estimates for returning student enrollment. All outcomes are measured in logarithmic form.

enrollment declines. Moreover, both students and institutions face significant disruptions, but their vulnerabilities are distinct. Students who are more vulnerable to hurricane disruptions tend to be those from low-income backgrounds or those relying on local institutions, particularly those attending community colleges. Conversely, institutions, especially two-year colleges, are vulnerable due to their dependence on local student populations and state or local funding, which can decline following a hurricane.

From a policy perspective, while addressing students' immediate needs, such as financial aid and support services, is crucial, we believe that strengthening the institutions themselves may offer a more sustainable solution. Ensuring that colleges, especially community colleges, have the resources to remain operational and recover quickly will mitigate long-term educational disruptions. This also aligns with our findings that increasing government funding to colleges can help address the challenges posed by both student and institutional vulnerabilities. Therefore, policies that not only provide immediate relief but also promote long-term investments in educational recovery programs are necessary to ensure that higher education systems are not only restored but strengthened, enabling students to persist and complete their education despite the challenges posed by natural disasters.

8. Conclusion

The climate change, heightened temperatures and a surge in the frequency of natural calamities, have exerted discernible effects across multiple dimensions of our society, causing substantial societal losses. This study capitalizes on the incidence of hurricanes within the United States as a lens through which to scrutinize their influence on a specific facet: higher education. Analyzing administrative data from higher education institutions, the study uncovers significant trends in the aftermath of hurricanes. Specifically, within a decade following a hurricane, two-year community colleges witness 10 %–14 % decline in FTE enrollments and total degree and certification conferrals. In contrast, four-year institutions do not exhibit significant changes in enrollment or completion post-hurricane. These findings underscore the vulnerability of two-year colleges to natural disasters and highlight the need for targeted support and intervention in these institutions.

The broader implications of these findings extend beyond the immediate financial costs of natural disasters. Federal Emergency

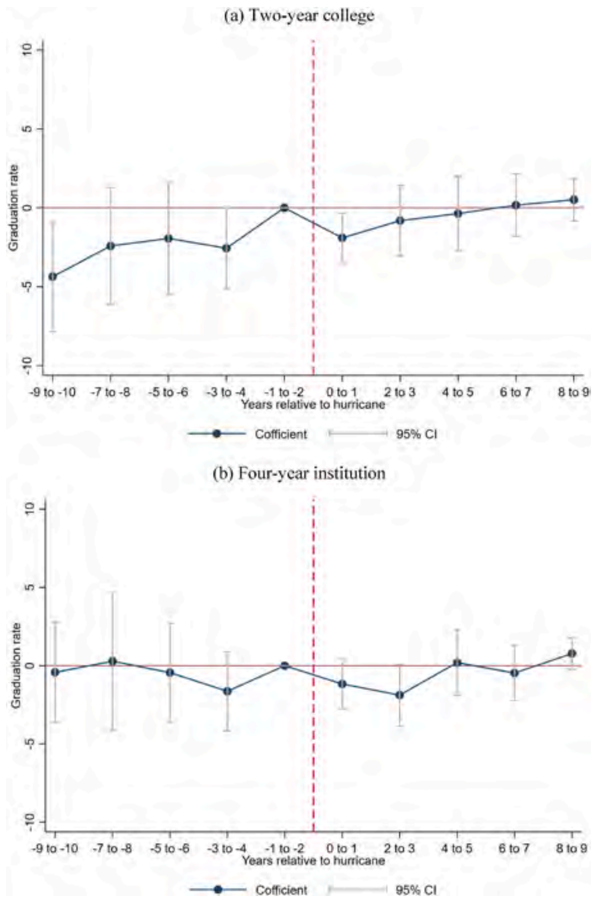

Fig. 7. The Effects of Hurricanes on College Graduation Rate
Notes: This figure illustrates the point estimates and 95 % confidence intervals of the dynamic effects of hurricanes on graduation rates. The college graduation rate is defined by IPDES as the percentage of students who completed a degree or certificate within 150 % of the normal time.

Management Agency (FEMA)'s damage and cost assessments typically focus on direct physical destruction and short-term economic disruptions. However, this study presents evidence that natural disasters also significantly impede human capital accumulation, a critical component of long-term economic and social development. At the same time, the impact of natural disasters on human capital accumulation is uneven. Our research shows that vulnerable groups are likely to be more affected, further exacerbating social inequalities. The marked and lasting effects on higher education suggest that the societal costs of natural disasters may far exceed FEMA's official estimates. Furthermore, the long-term implications of natural disasters on higher education are not limited to enrollment and degree attainment. The aftermath of natural disasters may also affect future earnings potential, career trajectories, and overall well-being of affected individuals. Reduced educational attainment can lead to lower lifetime earnings, diminished career prospects, and increased reliance on social safety nets. This, in turn, can exacerbate socioeconomic inequalities and hinder community recovery and resilience.

In conclusion, this study contributes to the growing body of literature on the economic and social impacts of natural disasters. By highlighting the specific vulnerabilities of higher education institutions, particularly two-year colleges, it underscores the need for targeted interventions and increased financial support to mitigate the adverse effects of hurricanes. As climate change continues to intensify the frequency and severity of natural disasters, understanding and addressing their impacts on higher education will be crucial for building resilient and equitable communities.

CRediT authorship contribution statement

Fanyu Liu: Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Kerui Geng:** Writing – original draft, Visualization, Software, Methodology. **Feng Chen:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

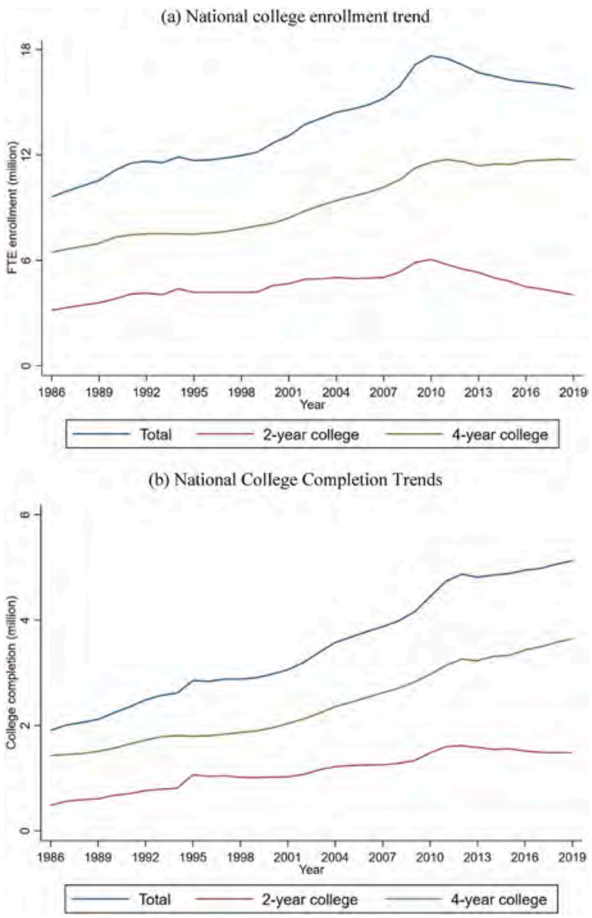

Fig. A1. National College Enrollment and Completion Trends (a) National college enrollment trend
Notes: These figures display the national college FTE enrollment and the total number of degrees or certifications awarded from 1986 to 2019, categorized by institution type. Data are sourced from IPEDS.

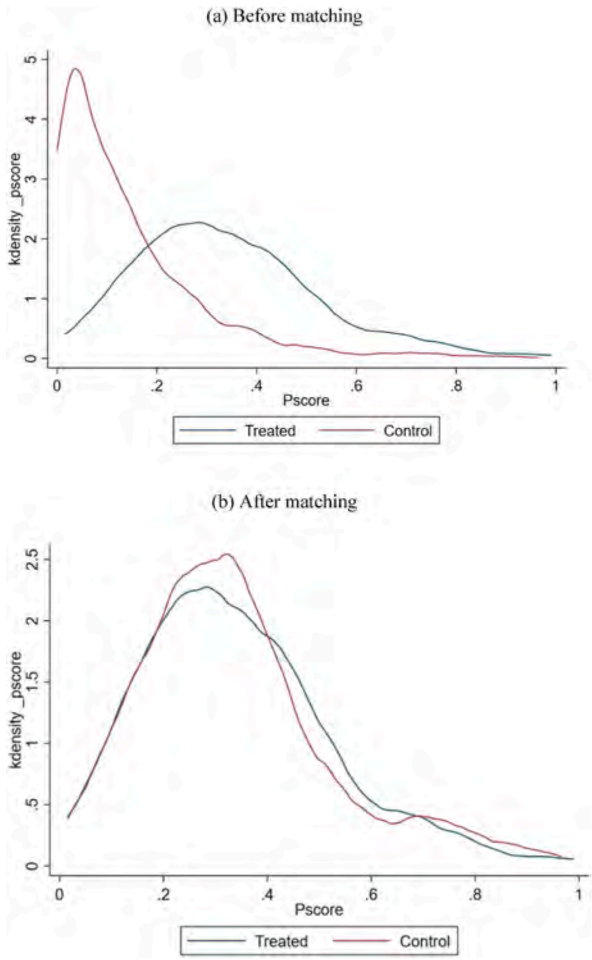

Fig. A2. Kernel Density Plots before and after Matching
Notes: This figure presents Kernel density plots comparing the distribution of propensity scores for the treated and control groups before and after the 1:1 nearest-neighbor propensity score matching, demonstrating improved balance in covariates between treated and control units.

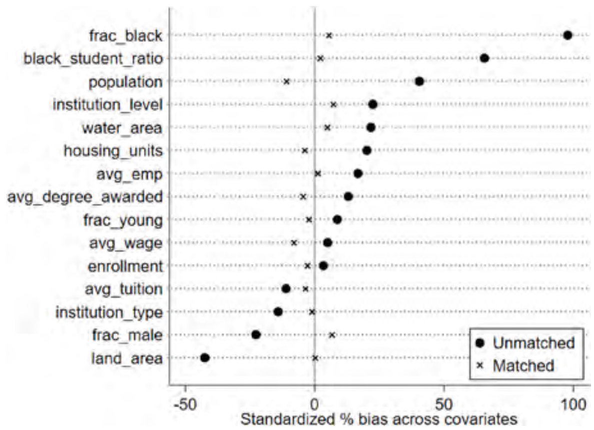

Fig. A3. Balance Test of Matching Variables
Notes: These figures present the balance test of matching variables, illustrating the distribution of covariates before and after matching to assess the effectiveness of the propensity score matching procedure.

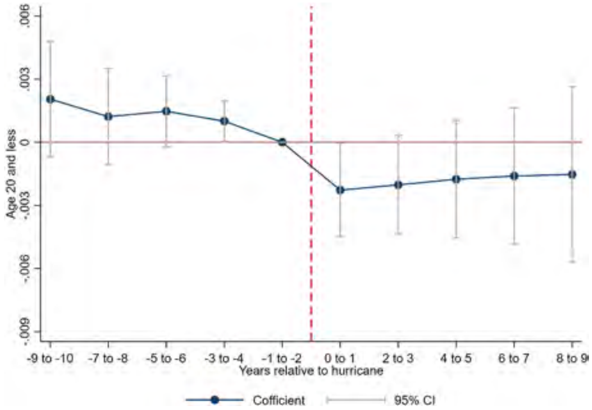

Fig. A4. The Effects of Hurricanes on the Proportion of the Population Aged 20 and Less
Notes: This figure illustrates the point estimates and 95 % confidence intervals of the dynamic effects of hurricanes on demographic change (age 20 and less).

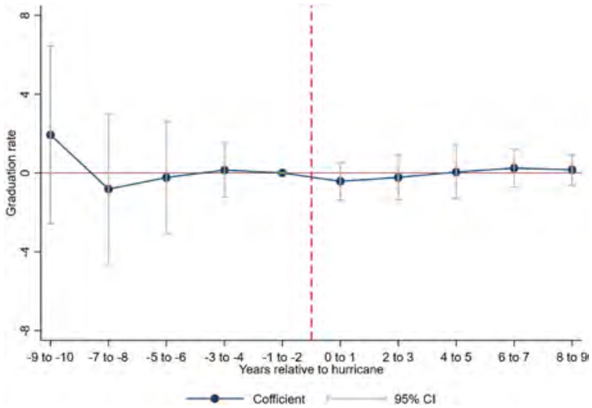

Fig. A5. The Effects of Hurricanes on High School Graduation Rate
Notes: This figure illustrates the point estimates and 95 % confidence intervals of the dynamic effects of hurricanes on high school graduation rates.

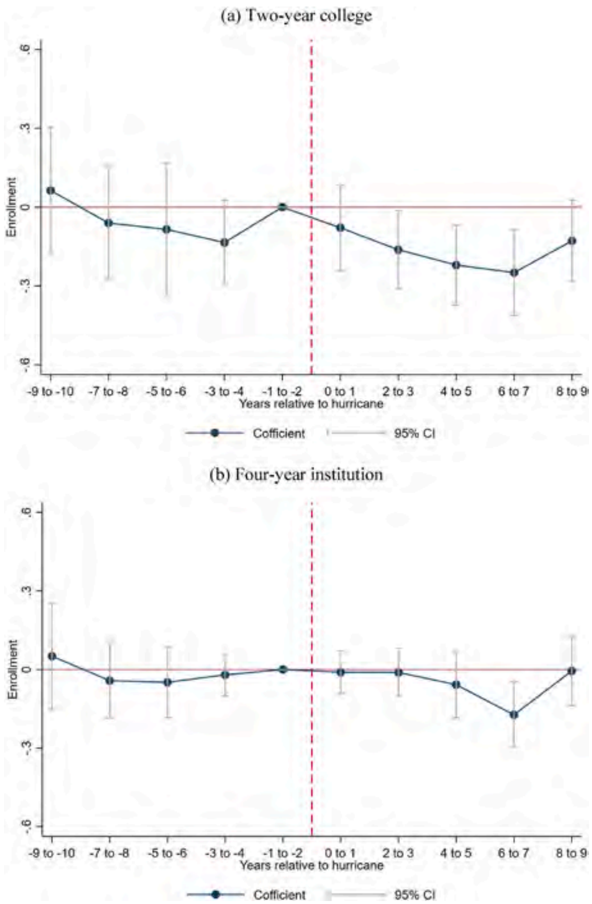

Fig. A6. The Effects of Hurricanes Freshman Enrollment from High School
Notes: This figure illustrates the point estimate and 95 % confidence internals of the dynamic effects of hurricanes on freshman enrollment among high school graduates from the previous 12 months.

Table A1
Hurricane Landfalls in the Continental United States

Year	Month	Saffir-Simpson Category	Max Wind (kt)	Name
1980	Aug	3	100	Allen
1983	Aug	3	100	Alicia
1984	Sep	2	95	Diana
1985	Jul	1	65	Bob
1985	Aug	1	80	Danny
1985	Sep	3	100	Elena
1985	Sep	3	90	Gloria
1985	Oct	1	75	Juan
1985	Nov	2	85	Kate
1986	Jun	1	75	Bonnie
1986	Aug	1	65	Charley
1987	Oct	1	65	Floyd
1988	Sep	1	70	Florence
1989	Aug	1	70	Chantal
1989	Sep	4	120	Hugo
1989	Oct	1	75	Jerry
1991	Aug	2	90	Bob
1992	Aug	5	145	Andrew
1993	Aug	3	100	Emily
1995	Aug	2	85	Erin
1995	Oct	3	100	Opal
1996	Jul	2	90	Bertha
1996	Sep	3	100	Fran
1997	Jul	1	70	Danny

(*continued on next page*)

Table A1 (*continued*)

Year	Month	Saffir-Simpson Category	Max Wind (kt)	Name
1998	Aug	2	95	Bonnie
1998	Sep	1	70	Earl
1998	Sep	2	90	Georges
1999	Aug	3	100	Bret
1999	Sep	2	90	Floyd
1999	Oct	2	95	Irene
2002	Oct	1	80	Lili
2003	Jul	1	80	Claudette
2003	Sep	2	90	Isabel
2004	Aug	1	70	Alex
2004	Aug	4	130	Charley
2004	Aug	1	65	Gaston
2004	Sep	2	90	Frances
2004	Sep	3	105	Ivan
2004	Sep	3	105	Jeanne
2005	Jul	1	65	Cindy
2005	Jul	3	105	Dennis
2005	Aug	3	110	Katrina
2005	Sep	1	65	Ophelia
2005	Sep	3	100	Rita
2005	Oct	3	105	Wilma
2007	Sep	1	80	Humberto
2008	Jul	1	75	Dolly
2008	Sep	2	90	Gustav
2008	Sep	2	95	Ike
2011	Aug	1	75	Irene
2012	Aug	1	70	Isaac
2012	Oct	1	65	Sandy
2014	Jul	2	85	Arthur
2016	Sep	1	70	Hermine
2016	Oct	2	85	Matthew
2017	Aug	4	115	Harvey
2017	Sep	4	115	Irma
2017	Oct	1	65	Nate
2018	Sep	1	80	Florence
2018	Oct	5	140	Michael
2019	Jul	1	65	Barry
2019	Sep	2	85	Dorian

Note: This table lists all hurricanes that made landfall in the continental United States from 1980 to 2019. The "Saffir-Simpson Category" indicates the hurricane's classification on the Saffir-Simpson Hurricane Wind Scale at the time of landfall, based on estimated maximum sustained (1-min) surface winds measured at a 10-m elevation. "Maximum Winds" refers to the highest estimated sustained surface winds recorded along the U.S. coast during landfall. Data are sourced from the Hurricane Research Division (HRD) database.

Table A2
Number of Counties by Hurricane Frequency

Frequency	Number	Percentage %
1	272	51.03
2	136	25.52
3	70	13.13
4	26	4.88
5+	29	5.44
Total	533	100

Notes: This table reports the number of counties affected by hurricanes, categorized by the frequency of hurricane strikes between 1980 and 2019. The frequency is measured on a yearly basis, meaning that if multiple hurricanes impacted a county within the same year, it is counted as a single occurrence.

Table A3
Robustness Checks Including State-Specific Linear Time Trend

	(1)	(2)	(3)	(4)
	Enrollment		Completion	
	Two-year	Four-year	Two-year	Four-year
0–4 years	−0.080***	0.008	−0.136***	0.004
	(0.021)	(0.015)	(0.024)	(0.016)
5–9 years	−0.110***	0.022	−0.176***	−0.012
	(0.027)	(0.021)	(0.031)	(0.023)
R Square	0.937	0.965	0.880	0.948
Observations	41,270	30,427	41,270	30,427
County covariates	Yes	Yes	Yes	Yes
Institution covariates	Yes	Yes	Yes	Yes
Institution FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Event time FE	Yes	Yes	Yes	Yes
State-by-year FE	Yes	Yes	Yes	Yes

Notes: This table presents the estimated effects of hurricanes on college enrollment and completion using the Sun and Abraham (2021) estimator, incorporating state-specific linear time trends. For details on the outcome variables, control variables, fixed effects, and sample weights, please refer to the notes in Table 2. Standard errors are clustered at the county level and reported in parentheses. Statistical significance levels: *p < 0.10; **p < 0.05; ***p < 0.01.

Table A4
Parallel Trends Test for Student Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	In-state student		White		Black		Hispanic	
	Two-year	Four-year	Two-year	Four-year	Two-year	Four-year	Two-year	Four-year
−2~-3 years	0.662	0.206	−0.878*	0.678	−0.177	−0.076	−0.215	−0.214
	(1.538)	(0.981)	(0.516)	(0.546)	(0.414)	(0.264)	(0.424)	(0.222)
−4~-5 years	1.927	0.411	−1.044	0.275	−0.224	−0.328	−0.312	0.020
	(1.686)	(2.166)	(0.787)	(0.720)	(0.625)	(0.371)	(0.616)	(0.247)
−6~-7 years	−0.853	−1.204	−0.271	−0.340	−0.575	0.120	−0.762	0.460
	(1.777)	(2.260)	(0.951)	(0.739)	(0.892)	(0.464)	(0.631)	(0.287)
−8~-9 years	1.493	−0.118	−0.813	−0.945	−0.709	0.239	−0.220	0.672**
	(1.400)	(1.503)	(1.152)	(1.033)	(1.040)	(0.544)	(0.841)	(0.343)
County covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Institution covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Institution FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Event time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-by-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table presents the parallel trends test of hurricanes on student characteristics using the Sun and Abraham (2021) estimator. "In-state student" refers to the share of students from within the state, while "White", "Black", and "Hispanic" indicate the percentage of students identifying as white, black, and Hispanic, respectively, and they are excluded from control variables when using as the outcome variable. For details on other control variables, fixed effects and sample weights, please refer to the notes in Table 2. Standard errors are clustered at the county level and reported in parentheses. Statistical significance levels: *p < 0.10; **p < 0.05; ***p < 0.01.

Table A5
Robustness Checks Using Alternative Staggered DiD Methods

	(1)	(2)	(3)	(4)
	Enrollment		Completion	
	Two-year	Four-year	Two-year	Four-year
Panel A. Borusyak et al. (2024)				
Hurricane*Post	−0.070***	0.018	−0.086***	−0.002
	(0.025)	(0.031)	(0.025)	(0.008)
Observations	41,270	30,427	41,270	30,427
Panel B. Callaway and Sant'Anna (2021)				
Hurricane*Post	−0.172***	0.027	−0.071**	−0.043*
	(0.023)	(0.020)	(0.028)	(0.024)
Observations	41,270	30,427	41,270	30,427
County covariates	Yes	Yes	Yes	Yes
Institution covariates	Yes	Yes	Yes	Yes

(*continued on next page*)

Table A5 (*continued*)

	(1)	(2)	(3)	(4)
	Enrollment		Completion	
	Two-year	Four-year	Two-year	Four-year
Institution FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Event time FE	Yes	Yes	Yes	Yes
State-by-year FE	Yes	Yes	Yes	Yes

Notes: This table presents the difference-in-differences (DiD) estimates of the effects of hurricanes on college enrollment and completion, using estimators developed by Borusyak et al. (2024) and Callaway and Sant'anna (2021). The variable *Hurricane* is a binary indicator for county exposure to hurricanes during the sample period, while *Post* denotes the period following a hurricane strike. For details on the outcome variables, control variables, fixed effects, and sample weights, see the notes in Table 2. Standard errors, clustered at the county level, are reported in parentheses. Statistical significance levels are denoted as follows: *p $<$ 0.10; **p $<$ 0.05; ***p $<$ 0.01.

Table A6
Differential Effects of Hurricanes: Category 2 and Higher vs. Category 1

	(1)	(2)	(3)	(4)
	Enrollment		Completion	
	Two-year	Four-year	Two-year	Four-year
0–4 years	−0.021	−0.027	−0.038	0.038
	(0.025)	(0.023)	(0.034)	(0.031)
5–9 years	−0.038	0.004	−0.011	0.020
	(0.028)	(0.026)	(0.031)	(0.029)
R-Square	0.932	0.968	0.884	0.953
Observations	19,827	13,231	19,827	13,231
County covariates	Yes	Yes	Yes	Yes
Institution covariates	Yes	Yes	Yes	Yes
Institution FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Event time FE	Yes	Yes	Yes	Yes
State-by-year FE	Yes	Yes	Yes	Yes

Notes: This table reports the estimated differential effects of hurricanes, comparing category 2 and higher (treated) with category 1 (control), on college enrollment and completion. The analysis employs the estimator developed by Sun and Abraham (2021). For details on the outcome variables, control variables, fixed effects and sample weights, see the notes in Table 2. Standard errors, clustered at the county level, are shown in parentheses. Statistical significance levels are indicated as follows: *p $<$ 0.10; **p $<$ 0.05; ***p $<$ 0.01.

Table A7
Robustness Check Controlling for In- and Out-Migration

	(1)	(2)	(3)	(4)
	Enrollment		Completion	
	Two-year	Four-year	Two-year	Four-year
0–4 years	−0.070**	−0.021	−0.052*	0.031
	(0.028)	(0.025)	(0.028)	(0.027)
5–9 years	−0.077***	−0.031	−0.055*	0.018
	(0.029)	(0.031)	(0.031)	(0.036)
R-Square	0.937	0.966	0.881	0.949
Observations	37,924	26,965	37,924	26,965
In- and out-migration	Yes	Yes	Yes	Yes
County covariates	Yes	Yes	Yes	Yes
Institution covariates	Yes	Yes	Yes	Yes
Institution FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Event time FE	Yes	Yes	Yes	Yes
State-by-year FE	Yes	Yes	Yes	Yes

Notes: This table reports the estimated effects of hurricanes on college enrollment and completion using the estimator developed by Sun and Abraham (2021). The analysis includes the number of outflow and inflow migrants as controls. For details on the outcome variables, control variables, fixed effects, and sample weights, see the notes in Table 2. Standard errors, clustered at the county level, are shown in parentheses. Statistical significance levels are indicated as follows: *p $<$ 0.10; **p $<$ 0.05; ***p $<$ 0.01.

Table A8
The Effects of Hurricanes on College Revenues

	State and local appropriations		Federal appropriations		Tuition fee	
	Two-year	Four-year	Two-year	Four-year	Two-year	Four-year
Panel A: Institutional measure						
0–4 years	−0.054*	0.022	−0.102	0.261	−0.028	0.003
	(0.031)	(0.031)	(0.120)	(0.183)	(0.039)	(0.022)
5–9 years	−0.103**	0.018	−0.058	0.305	−0.053	−0.005
	(0.044)	(0.027)	(0.191)	(0.246)	(0.048)	(0.030)
Mean (in thousand)	19,492	46,519	840	5690	5620	48,392
R-Square	0.978	0.995	0.912	0.955	0.787	0.959
Observations	8642	5219	6780	6214	33,645	29,146
Panel B: Per Student measure						
0–4 years	−0.020	−0.011	−0.110	0.404**	−0.021	0.006
	(0.033)	(0.027)	(0.130)	(0.188)	(0.041)	(0.019)
5–9 years	−0.052	−0.038	−0.020	0.477*	−0.047	0.006
	(0.038)	(0.037)	(0.196)	(0.248)	(0.046)	(0.023)
Mean	10,859	5762	1508	2531	9885	14,080
R-Square	0.906	0.976	0.938	0.939	0.787	0.873
Observations	8642	5219	6780	6214	33,645	29,146
County covariates	Yes	Yes	Yes	Yes	Yes	Yes
Institution covariates	Yes	Yes	Yes	Yes	Yes	Yes
Institution FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Event time FE	Yes	Yes	Yes	Yes	Yes	Yes
State-by-year FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table presents the estimated effects of hurricanes on college revenues, utilizing the estimator developed by Sun and Abraham (2021). Panel A reports findings for total institutional measures of state appropriations, federal appropriations, and tuition fees, while Panel B provides estimates for the per-student measures of these variables. The control variables, fixed effects, and sample weights align with those used in Table 2. Standard errors, clustered at the county level, are reported in parentheses. Statistical significance levels are denoted as follows: *p $<$ 0.10; **p $<$ 0.05; ***p $<$ 0.01.

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