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Natural disasters and high-stakes exam performance: Evidence from the 2008 Wenchuan earthquake

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ABSTRACT

In this study, the 2008 earthquake in Wenchuan, China serves as a natural experiment for examining the effect of natural disasters on high-stakes exam performance among students who were admitted to four-year colleges between 2005 and 2011. Results of a generalized difference-in-differences model show that, on average, the earthquake reduced a student's National College Entrance Examination (NCEE) standard score by 55% of a standard deviation. The findings have implications for higher education and China's economy, because earthquake exposure lowers a student's probability of being accepted to an elite college, pursuing a major in a high-salary field, and moving to a highly developed urban area for education or employment.

1. Introduction

Large-scale and unpredictable natural disasters, like other exogenous shocks such as famines and conflicts, can devastate communities. A handful of researchers have recently tried to quantify the impact of natural shocks on both individual and societal well-being. Studies have focused on earthquakes (Blumenstock, Eagle, & Fafchamps, 2016; Filipski, Jin, Zhang, & Chen, 2019; Gignoux & Menéndez, 2016; Hombrados, 2020; Sinding Bentzen, 2019), tsunamis (e.g. Cas, Frankenberg, Suriastini, & Thomas, 2014; Heger & Neumayer, 2019; Lynham, Noy, & Page, 2017), and hurricanes (Belasen & Polachek, 2008; de Oliveira, Lee, & Quintana-Domeque, 2021; Özek, 2021; Strobl, 2012). Economic research on disasters and their consequences, however, is still limited. This study makes a critical contribution by examining the causal effect of a large natural disaster on students' educational achievement, and the associated implications for a major global economy.

The Wenchuan earthquake occurred in May of 2008, about one month before China's National College Entrance Exam (NCEE), commonly known as the *Gaokao* in Chinese. The NCEE, usually held each year on June 7th and 8th, is a prerequisite for Chinese students to enter university. In 2008, China's Ministry of Education postponed the NCEE until early July in 40 earthquake-affected counties in Sichuan province to relieve stress on students and families. >100,000 students took the delayed exam with a separate admission process. The NCEE returned to its previous format the following year, meaning that younger students who were affected by the earthquake competed with their counterparts from non-affected regions in Sichuan. This study explores whether those students who experienced the earthquake scored lower than their unaffected peers on the NCEE, to assess whether exposure to a large-scale natural disaster is associated with performance in a high-stakes exam and the resulting eligibility for postsecondary education.

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Two unique datasets are analyzed in this study: geographical data on the intensity distribution of the 2008 Wenchuan earthquake and a national administrative dataset on China's college entrance examinations. The first contains detailed information on different exposure levels to the earthquake in China. The second provides the county identifier and the total test score for all students who were admitted to Chinese four-year colleges between 2005 and 2011.

By matching these two datasets, we estimate how natural disasters affect students' academic achievement in a high-stakes setting. Our baseline results show that in this sample, on average, students affected by the earthquake experienced a 55% standard deviation decrease in the NCEE standard score. The results are robust to a rich set of robustness checks and placebo tests. Moreover, heterogeneity tests reveal that the negative impacts of earthquake exposure were stronger for students in the liberal arts tracks and students with relatively low performance on the exam.

We further explore the implications of these findings by investigating the relevant educational and economic consequences of a performance decline in a high-stakes exam. We first confirm that earthquake exposure caused a significant decrease in enrollment in elite colleges, such as Project 211 colleges, for the students in this study. We then demonstrate that for the subgroup of students admitted to elite colleges, quake-affected students were squeezed out of majors in high-salary fields such as economics and finance. Finally, we match geographical data to show that earthquake-affected students were less likely to go to prosperous cities in China's highly developed regions for their higher education.

This paper builds on a small body of literature that examines the impacts of natural disasters on society and individuals.[1] Interestingly, recent work in this area describes how natural disasters can, under certain conditions, increase long-term economic output (Heger & Neumayer, 2019), decrease income inequality (Keerthiratne & Tol, 2018), reduce crime (Hombrados, 2020), and improve girls' educational attainment (Liu & Xu, 2021).[2] Also, existing studies that link natural disasters to negative effects on educational attainment for the affected (Caruso & Miller, 2015; Wang, Yang, & Li, 2017) or subsequent generations (Almond, 2006; Andrabi, Daniels, & Das, 2021; Caruso, 2017) generally measure impact in years of schooling.[3] Our main contributions beyond the extant work are that (1) we explore a more recent seismic event and the worst natural disaster recorded in China since 1976, and (2) we not only examine changes in academic performance but also investigate related outcomes such as college acceptance, choice of major, and the location of the higher education institution attended.

In addition, this paper enriches the existing body of knowledge on high-stakes exam performance. In many countries, high-stakes testing is used to rank students for college admission, and students who score lower than expected on their college entrance examinations often have to wait an entire year before taking them again, potentially creating high opportunity or stigma costs of retaking the exam (Park, 2020). There exists a burgeoning economic literature estimating how random disturbance can impede cognitive performance during high-stakes exams. Yet cognitive burden created by heat waves (Park, 2020; Zivin, Song, Tang and Zhang, 2020), air pollution (Ebenstein, Lavy, & Roth, 2016; Zivin, Liu, Song, Tang and Zhang, 2020), or pollen inhalation (Bensnes, 2016) tend to be relatively low and short-lived. Natural disasters, on the other hand, can exert long-lasting effects on health and education.

Previous studies suggest that disaster exposure as early as in utero can exert considerable influence over the growth of human capital (Almond, 2006; Caruso & Miller, 2015; Lin & Liu, 2014). Our results confirm a similar sustained effect, leading us to recommend that the government should develop a coherent education policy to increase access to adequate educational opportunities for young people from communities affected by a natural disaster. Since the damaging effects are likely to be heterogeneous across students, policy and financial supports should be designed to reach students at different levels of achievement and students from disadvantaged backgrounds. In sum, much remains to be done to improve relief efforts before the next disaster strikes.

This paper is organized as follows. Section 2 presents a brief overview of the 2008 Wenchuan earthquake. Section 3 describes the data obtained from various sources. Section 4 reports the main findings and results from a series of robustness checks, followed by heterogeneity analyses. Section 5 discusses the implications of the findings for educational and economic welfare in China. Section 6 concludes.

2. The 2008 Wenchuan earthquake

On May 12, 2008, at approximately 14:28 local time, an earthquake of magnitude 8.0 on the Richter scale struck the southwest region of China. The epicenter, Wenchuan county in Sichuan province, was located 100 km northwest of Chengdu and had a population exceeding 111,000 inhabitants before the earthquake hit. According to the Records of the Great Wenchuan Earthquake Relief Efforts (hereafter, RGWERE), officially published by the Compilation Committee on Rescue Work after the Wenchuan Earthquake

[1] Sometimes, disasters can be man-made. Recent research by Guo (2020) found that, due to U.S. bombing campaigns in Laos, unexploded ordnance not only interrupts the education of war-time cohorts, but also has strong negative impacts on the education attainment of post-war cohorts.

[2] The empirical literature does not offer conclusive evidence on these issues. For example, partly depending on the objects studied and the datasets used, the impacts of natural disasters on economic growth could be substantially negative (Felbermayr & Gröschl, 2014) or negligible (Cavallo et al., 2013).

[3] For instance, Almond (2006) used the 1918 influenza pandemic as a natural experiment, finding that cohorts in utero during the pandemic displayed reduced educational achievement. Using Peruvian census data from 1993 and 2007, Caruso and Miller (2015) showed that students affected by the 1970 Ancash earthquake completed less schooling (0.5 fewer years for males and 0.8 for females), and children of mothers affected by the earthquake also had 0.4 fewer years of education. Wang et al. (2017) found that among cohorts potentially affected by the 1976 Tangshan earthquake, average schooling years were about 0.14 to 0.21 years fewer than among non-affected cohorts.

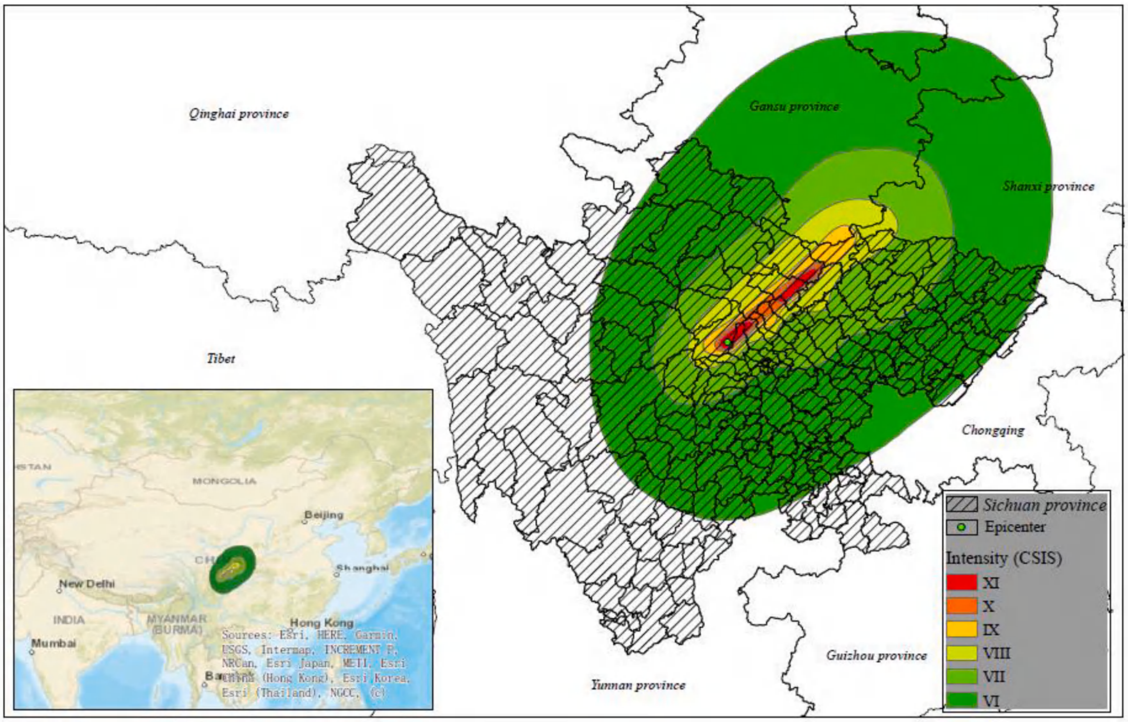

Fig. 1. 2008 Wenchuan earthquake intensity.
Notes: This map depicts the intensity of the Wenchuan earthquake, measured by China seismic intensity scale (CSIS).

(2017), the disaster-affected areas ranged from Haiyuan county in China's northern Ningxia province to Yongshan county in southern Yunnan province. Fig. 1 depicts the intensity distribution of the earthquake according to China seismic intensity scale (CSIS), which gives an idea of how communities experienced the earthquake in different regions around the epicenter.

The main shock of the Wenchuan earthquake lasted approximately three minutes, leading to mass casualties. According to Chinese state officials, the earthquake caused 69,226 known deaths, of which 68,636 were in Sichuan province; and nearly 375,000 were injured by falling debris and building collapses. This estimate includes 158 earthquake relief workers who were killed in landslides as they tried to repair roads (Yong & Booth, 2011). A month after the earthquake, nearly 20,000 people remained missing, while five million were rendered homeless. Specifically, over 7000 schoolrooms collapsed in the course of the earthquake, mostly in rural areas, reportedly leading to the death of nearly 5000 students and the injury of over 15,000 students.

The earthquake destroyed over 950 million square feet of commercial property and affected infrastructure such as transportation and power facilities. In total, the Wenchuan earthquake caused a direct economic loss of about 845.14 billion yuan (USD 121.6 billion). As an economically developed province in southwest China, Sichuan ranked 10th in the country in terms of industrial added value (IAV) in 2007. Official estimates of the direct economic losses to the industrial sector in Sichuan's ten most affected counties were reported at 40.5 billion yuan (USD 5.83 billion), accounting for about two-thirds of the total losses throughout the province. Sichuan is also a major agricultural province in China, boasting the nation's highest pork production: Sichuan was responsible for producing 9.52% of China's pork in 2007. The direct economic losses to agriculture among the ten most damaged counties were estimated at 15 billion yuan (USD 2.16 billion), >40% of the total agricultural losses in the province. In addition, the earthquake knocked out electricity in over five counties, leaving residents in several of the worst affected regions without running water. Concomitant income losses and a declining standard of living would inevitably lead to declines in academic performance.

Recovery of damaged education facilities was a major challenge after the disaster. 16 months after the earthquake, nearly 10% of primary and secondary school students had still not been moved into permanent school buildings (Zhang, 2009). Students in some destroyed regions had to transfer to neighboring districts to continue their studies while their school buildings were repaired and rebuilt. For instance, surviving students and faculty from Beichuan middle school – which totally collapsed in the earthquake – were relocated to the downtown area of Mianyang city to live and attend school for about two years (Compilation Committee on Rescue Work after the Wenchuan Earthquake, 2017). Meanwhile, the central government launched an extensive program to rebuild schools and communities in the earthquake zone. Former president Hu Jintao's call in the aftermath of the quake for schools to become safe places was followed by a commitment from the government to spend an extra RMB 8 billion (US$1.17 billion) on earthquake proofing schools (Roney, 2011).

Though the government is rightly applauded for its relief and reconstruction effort, many unmet needs still existed in the areas. One of the most pressing educational problems, according to Menefee and Nordtveit (2012), was that high school students were planning to drop out of school to look for work to help support their families. In other words, quake-affected students might give up on the NCEE or have no time and energy left to prepare for the exam. Notice that low-SES students were usually more likely to drop out of school and forgo the exam, leading to the under-representation of the disadvantaged in the dataset studied.[4]Teenagers also constituted the most emotionally distraught age group in the disaster region, which commonly took a long time to recover (Wang et al., 2015; Ying, Wu, De Lin, & Chen, 2013). College entrance is, however, the most stressful experience typically shared by high school students in China. The earthquake therefore provides us with a quasi-natural experiment to test the relationship between earthquake exposure and academic performance in a high-stakes setting.

3. Data

3.1. County-level earthquake data

We sourced the intensity data from the International Knowledge Centre for Engineering Sciences and Technology (IKCEST), a globally connected engineering institution under the auspices of UNESCO.[5] The earthquake intensity is measured in six levels (VI to XI) using China seismic intensity scale (CSIS), similar to the Modified Mercalli Intensity (MMI) scale used in the US and the European macro seismic scales used in European countries. In the placebo test, we also used weak earthquakes recorded across Hunan, Jiangxi, and Guizhou province in 2009, which were derived from China Earthquake Networks Center (CENC).[6]

To empirically identify the causal educational impacts of the 2008 Wenchuan earthquake, we examine differences in standard scores between NCEE takers in affected and unaffected counties in Sichuan. We define a county as a treated one based on whether the location of its civic center was subject to earthquake intensities (CSIS) ranged from IX to XI. Because, first, most of a county's population, especially high school students, are concentrated in its civic center, instead of being uniformly distributed. Second, earthquake intensities above the threshold of CSIS IX are associated with much higher damage, as reflected in the intensity scale described in Appendix Table A1 and the statistics of casualties in Appendix Table A2. Appendix Fig. A1 shows the specific location of each treated county's civic center.

As such, we define Wenchuan, Beichuan, Mao, and Qingchuan county as the treated group. We used pre-earthquake county characteristics such as GDP per capita and the rate of people with agricultural *hukou* status as control variables. Furthermore, we utilized several alternative measures of the earthquake's force, including the distance to fault zone, the number of aftershocks, and causalities (see subsection 4.2.5). Our results are fully robust to these alternative proxies.

3.2. Administrative data on college admission

The NCEE varies slightly by province, but generally includes three compulsory tests: Chinese, mathematics, and a foreign language (usually English). If students choose a science track (*li-ke* in Chinese) in high school, they take additional tests related to physics, chemistry, and biology; if they choose an art/social science track (*wen-ke* in Chinese), the additional tests involve history, politics, and geography. Entry into a particular college is determined almost exclusively by how a students' NCEE score ranks against others in the same province and track that year.

We utilize a unique individual-level administrative dataset on college admissions in China. This dataset includes every student who took the NCEE and was admitted to a four-yea college between 2005 and 2011. In other words, the dataset is the population of the test takers admitted, and it does not include those not admitted to a four-year college. Indicators include the student's academic track in high school, ID number (which contains a six-digit code for the county of residence where the student was enrolled for the exam), NCEE total raw score, and the college and major to which the student was admitted. However, the dataset does not include demographic, SES-related, or other individual characteristics. This dataset allows us to analyze changes in test performance among students from different regions in a given province. The data also show whether or not a student was admitted to an elite university and a major in a high-salary field. We further investigate whether NCEE takers' geographical preferences for college changed after the earthquake.

Some exam takers may not be admitted to a college in a given year because of various reasons. First, their scores might be below the passing score of the college that they had applied to. This is very likely especially when the admission process was under the Boston mechanism instead of the Chinese parallel mechanism (Bo, Liu, Shiu, Song, & Zhou, 2019). In this case, they might not be observed in the dataset because of the mismatch. Second, they might choose to postpone their application and re-take the exam next year.[7] This is very likely when an examinee did not prepare well for the exam and was unsatisfied with his or her performance. Third, frustrated students who simply failed or gave up on the exam were also not within the scope of this study. Their scores were usually lower than the minimum requirements of being admitted to any college.

All the issues mentioned above may raise the concern of sample selection. For the first issue, although Sichuan province has changed the admission system from a Boston mechanism to the Chinese parallel mechanism since 2009, the impact could be accounted for by the year fixed effects in the DID setup. For the second and third issues, we think it is reasonable to assume that students in the

[4] This potential bias from selective participation is likely to result in a downward bias. Therefore, we may underestimate earthquake damage due to the low-SES dropout students from quake-affected regions.

[5] For more detailed information, see http://www.ikcest.org/index.htm

[6] CENC has been recording earthquakes worldwide since Jan 1, 2009, and it is free to query and download the data of each earthquake recorded. See https://data.earthquake.cn/datashare/report.shtml?PAGEID=earthquake_zhengshi

[7] Due to data limitations, we could not distinguish between first-time and repeat test-takers.

Table 1
Administrative data on college admission in Sichuan province.

Year	# of Students	# of Students in four Treated counties	% of Students in four Treated counties
2005	88,162	421	0.48%
2006	109,144	550	0.50%
2007	112,741	619	0.55%
2008	125,368	591	0.47%
2009	131,854	746	0.57%
2010	137,836	715	0.52%
2011	135,215	639	0.47%

Notes: This table presents basic descriptive statistics for administrative data on college admission in Sichuan province. The four treated counties identified are Wenchuan, Beichuan, Mao, and Qingchuan county, respectively.

Table 2
Summary statistics for the main variables of interest.

	Pre-period: 2005—2007		*Post-period: 2008—2011*	
Variables	Treated group	Control group	Treated group	Control group
Raw scores (science track)	553.2 (49.7)	547.6 (47.9)	485.7 (56.9)	504.7 (56.3)
Raw scores (liberal arts track)	542.7 (31.4)	531.6 (31.4)	502.1 (44.8)	513.3 (42.8)
% of students choosing the science track	74.3	73.4	71.9	71.1
% of students attending project 211 colleges	27	22.5	18	16.7
% of students eligible to apply for a first-tier college	39.5	32.5	18.4	22.5
Observations	1,590	3,08,457	2,691	5,27,582

Notes: Standard deviations are listed in parentheses.

treated counties were more likely to have difficulty preparing for or simply give up on the exam. If the proportion of low-achievers unobserved was higher in the treated counties than that in the control group, then our estimate would be an upper bound of the true performance decline. In other words, based on the truncated sample, we are likely to underestimate rather than overestimate earthquake damage.

Our main analyses focus on students in Sichuan who took the examination between 2005 and 2011. Summary statistics for the sample are reported in Table 1. Due to the recent massive expansion of higher education in China, the number of students admitted to university increased from 88,162 to 135,215 during the study period.

It is important to note that the exams and admissions in year 2008 were not consistent with other years. Due to the impact of the earthquake, in 2008, candidates from 40 disaster-stricken counties in Sichuan organized separate examinations and were admitted separately. The examination time, test papers and admission scores were all different from other non-affected areas in the province. Therefore, in 2008, the scores of candidates in disaster areas and non-disaster areas were not completely comparable. We could regard the effect in 2008 as a joint treatment of the disaster combined with relief aid (Andrabi et al., 2021). The inclusion of the 2008 sample does not affect analyses such as dynamic effects.[8]

3.3. Other data

The data on the several county-level variables were collected from various channels, including official websites, web services, and statistical yearbooks and annul reports. For instance, we gained the list of state-designated elite high schools in Sichuan via China Education and Research Network (CERNET), and verified each of them via its official website (if available) or *Baidu Baike*. The elevation data was obtained from Google earth. The numbers of county-level enrolled secondary students and faculty members were obtained from Sichuan statistical yearbooks. We provided a more detailed description of the data sources mentioned in Appendix Table A3.

3.4. Summary statistics

Table 2 reports summary statistics from our merged data on nearly one million exam takers in Sichuan from 2005 to 2011. The average raw NCEE score for students during the study period was 520 out of 750, with slightly more variation in the science track compared to the liberal arts track. Notice that before the earthquake occurred, students in treated counties performed relatively better compared to their counterparts in the control counties; however, this pattern reversed after the year 2008, reflecting a huge decline in academic performance in those affected regions. We transformed the raw scores into z-scores (i.e., standardized within year and track) in the analyses so that scores would be normalized and comparable across years. Additional summary statistics on county-level

[8] Excluding data from 2008 will not affect the conclusions of this paper.

Table 3
The impact of earthquake damage on high-stakes exam performance.

	(1)	(2)	(3)
Earthquake × Post	−0.547***	−0.549***	−0.529***
	(0.129)	(0.128)	(0.128)
Control × Post	N	Y	N
Control × Year trend	N	N	Y
County FE	Y	Y	Y
Track-by-year FE	Y	Y	Y
Number of counties	179	179	179
Observations	840,320	840,320	840,320
R-squared	0.056	0.056	0.057

Notes: This table reports the impact of the earthquake on students' standard NCEE scores within the pool of college starters in their province, year, and track, compared with those before the year 2008. Standard errors in parentheses are clustered at the county-year level. * denotes significance at 10%, ** at 5%, and *** at 1%.

characteristics are listed in Appendix Table A3.

4. Natural disasters result in decreased academic performance

4.1. A generalized difference-in-differences approach

4.1.1. Empirical strategy

We employed a generalized difference-in-differences framework to identify the causal effect of earthquake damage on students' academic achievement. The primary model specification used in the majority of our analyses is displayed below:

$$y_{ijt} = \beta Earthquake_j \times Post_t + \theta X_j \times Post_t + \lambda_j + \delta_{track} \times \gamma_t + \varepsilon_{ijt} \tag{1}$$

where y_{ijt} is the NCEE standard score of student i in county j in year t[9]; the dummy variable $Post_t$ is 0 for the years before 2008 and 1 for 2008 to 2011; $Earthquake_j$ is 1 for cohorts in treated counties and 0 otherwise. β is the coefficient of the core explanatory variable we are interested in, and it indicates how many standard deviations the test scores of candidates in hard-hit areas had changed compared to those in non-disaster areas. λ_j indicates county fixed effects to control for all time-invariant differences between counties. Since the design of the NCEE and exam difficulty varies by year and by track, we incorporate year-by-track fixed effects, denoted by $\delta_{track} \times \gamma_t$, to account for changes over time in a major track that affect exam takers similarly. X_j is a vector of pre-earthquake county-level controls, including GDP per capita in year 2005, the rate of people with agricultural *hukou* status in 2005, the number of enrolled secondary school students in 2005, whether a county had at least one state-designated elite high school in or before 2005, and the average elevation of each county's civic center. We incorporate the interaction term, $X_j \times Post_t$, to capture the economic, educational, and geographical endowments of each county, which may influence the earthquake intensity observed as well as the academic performance.[10] ε_{ijt} is the error term.

4.1.2. Main results

Table 3 presents results from a series of regression models estimating the effect of the earthquake on academic achievement. Column 1 displays the regression estimates with county and year-by-track fixed effects. Column 2 adds the control variables. Column 3 further replaces the post dummy with a linear year trend to test the sensitivity of our specification for the control variables. The regression estimates in column 2 represent our preferred specification and are used as the baseline for comparisons with most alternative specifications below. The estimated standard errors reported in parentheses are clustered at the county-year level to account for possible heteroscedasticity and serial correlation of the residuals, and the results are robust to alternative levels of clustering.

We found that earthquake damage led to about a 55% standard deviation decrease in NCEE standard scores for students in treated counties. The results remained stable after controlling for other pre-determined county-level characteristics. These impacts are particularly large and meaningful, when contrasting with short-term cognitive burden caused by random disturbance such as hot temperature and air pollution. For instance, Zivin, Hsiang, and Neidell (2018) found that a 1 °C increase in temperature during the exam period decreased total test scores by 1.2% of a standard deviation for young children across the United States. Although we do not control for temperature or air quality in the analysis, our results are not likely to be attributable to changes in random disturbance.

[9] A student i's NCEE z-score is calculated by: $zScore_{ikt} = \frac{x_{ikt} - \mu_{kt}}{\sigma_{kt}}$ where the subscript k means track(liberal arts/science) and t means year; x is a student's NCEE raw score in track k and year t; μ and σ represent for the mean value and standard deviation of the NCEE raw scores within a given year and track, respectively.

[10] Note that we do not control for time-varying county-level characteristics since they do not function well as controls, being outcome variables themselves that are likely distorted after the earthquake.

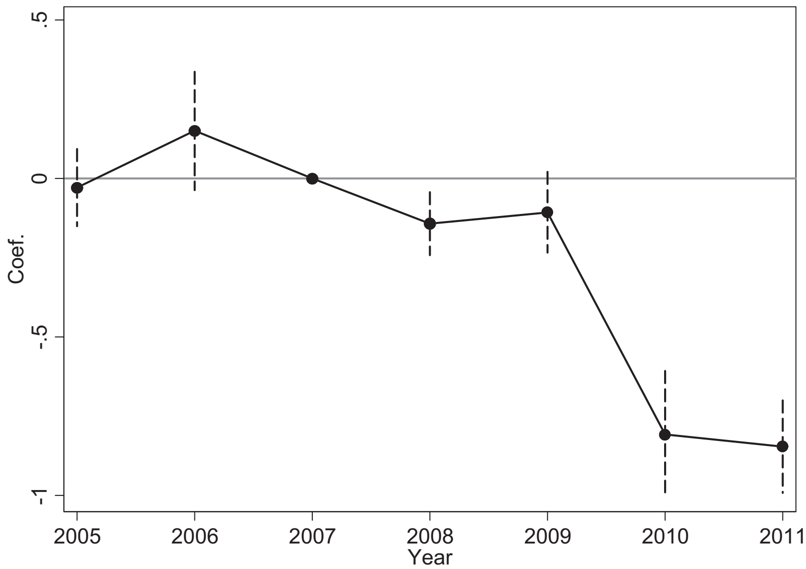

Fig. 2. Dynamic effects of earthquake damage on high-stakes exam performance.
Notes: This graph visualizes the dynamic effects of earthquake damage on students' academic performance using the year 2007 as the reference, where the solid lines connect the estimates and the dashed lines indicate the 95% confidence intervals.

4.2. Robustness checks

To ensure that our baseline findings can be interpreted as causal, we employed several robustness checks. The following sections present the results of the robustness checks.

4.2.1. Parallel test

Systematic differences between treated and control groups in pre-treatment conditions—in this case, students' pre-earthquake academic achievement—would violate the comparability of the counterfactuals for this quasi-natural experiment, because such differences are likely to affect each groups' performance after the earthquake. We found no systematic pre-treatment differences in our generalized difference-in-differences estimates. While the exact location and timing of an earthquake are determined by geographic happenstance, differences in disaster preparedness and migration efforts also represent potential systematic differences that could affect outcomes.

We first examined the link between earthquake damage and test performance year by year from 2005 to 2011. This approach allowed us to confirm there were no systematic differences in performance before the earthquake for exam takers in treated and control counties. The model specification is as follows:

$$y_{ijt} = \sum_{\tau=2005}^{2011} \beta_\tau Earthquake_j \times Year_\tau + \theta X_j \times Post_t + \lambda_j + \delta_{track} \times \gamma_t + \varepsilon_{ijt} \ (\tau \neq 2007) \tag{2}$$

where the year 2007 is left as a comparison.

The main results of the parallel test are presented in Fig. 2, where the solid lines connect the estimates and the dashed lines indicate 95% confidence intervals with standard errors clustered at the county-year level. Fig. 2 also confirms no systematic differences in the pre-trends, while showing that the negative impact of earthquake damage became larger in 2010 and 2011, two years after the earthquake. The magnitudes of the impacts were about -0.11 for 2008 and 2009 and around -0.83 for 2010 and 2011.

It is worth asking why the impact of the damage on test scores appears to be relatively small for the 2008 and 2009 cohorts. The impact in 2008 was relatively small, and one of the main reasons was that there was a special policy that allowed candidates in forty earthquake-affected counties to organize exams separately. In other words, the smaller impact at this time should be mainly due to the role of policy, rather than the fact that the test performance of candidates did not decline much.

Another possible reason has to do with students choosing to repeat the exam. Chinese students often choose to retake the grueling NCEE, aiming for a college with more prestige. For example, according to the China Educational Examination Yearbook, in year 2013, about 8.78 million students registered for the NCEE, of which 1.26 million were re-takers, accounting for nearly 15% of the total test takers (NEEA (National Education Examinations Authority), 2014). There is, however, a time and economic cost to repeat the college entrance examination. For example, a tuition fee is usually required for repetition courses - which can sometimes be high. Repeated candidates delay entry to college, which also means a delay in entering the workforce. Rational candidates will not always choose to repeat the college entrance examination. Repeating one or two years is the most common situation. For those candidates who did not

Table 4
Results of regression analysis using Placebo earthquake provinces.

	(1)	(2)	(3)	(4)
	Baseline	Placebo test		
	Sichuan	Guizhou	Hunan	Jiangxi
Earthquake × Post	−0.547***	−0.041	0.012	0.040
	(0.129)	(0.032)	(0.022)	(0.026)
County FE	Y	Y	Y	Y
Year-Track FE	Y	Y	Y	Y
Number of counties	179	88	113	97
Observations	840,320	408,683	766,657	639,312
R-squared	0.056	0.047	0.017	0.124

Notes: This table reports the impact of earthquake damage on the NCEE standard scores using students in Guizhou, Hunan, and Jiangxi as a placebo group, respectively. The specification is the same as that in column (1) of Table (4). Robust standard errors in parentheses are clustered at the county-year level. * denotes significance at 10%, ** at 5%, and *** at 1%.

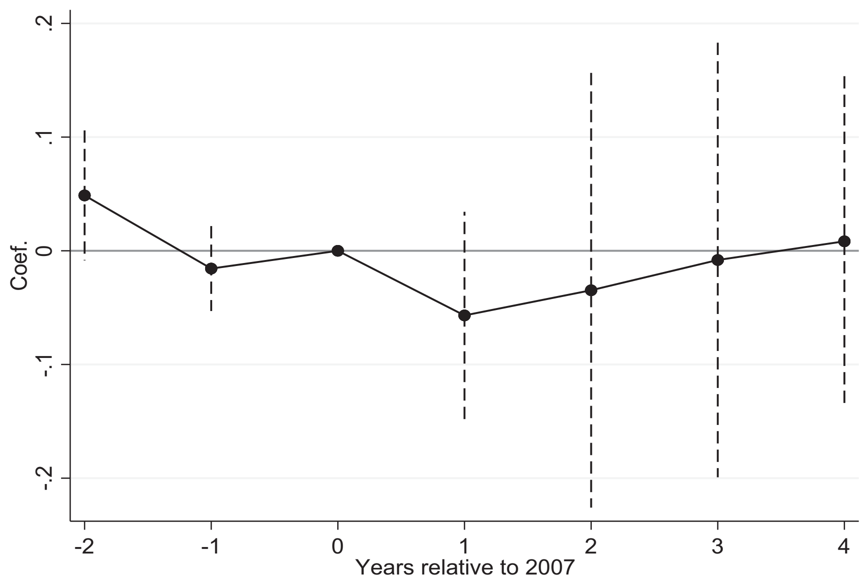

Fig. 3. Intra-province migration test using data on secondary school enrollment.
Notes: This graph visualizes the dynamic effects of earthquake damage on county-level secondary school enrollment using the year 2007 as the reference, where the solid lines connect the estimates and the dashed lines indicate the 95% confidence intervals.

perform well in 2008 or 2009 and chose to repeat, they were likely to appear in 2010 or 2011 cohort even if their scores were still not good after repeated studies. From this perspective, the effect of the earthquake on test takers in 2008 or 2009 may have been delayed due to the prevalence of retaking the NCEE.

Therefore, the dynamic effects shown in the article may not be able to accurately reflect the impact of the earthquake on the candidates of that year. In addition to the special policy in 2008, which made the impact smaller that year, students with unsatisfactory test scores often choose to decline an admission offer and repeat their studies. Due to data limitations, we are unable to distinguish whether a test taker was taking the test for the first time or taking the test again.

4.2.2. Placebo test

We next employed several placebo-based tests in which we produced simulated earthquake damage across three provinces based on the number of weak earthquakes (below a magnitude of IX) recorded in 2009.[11] Specifically, we selected Guizhou, Hunan, and Jiangxi as placebo provinces, as they are relatively comparable with Sichuan in terms of economic conditions and geographic location but were not affected by the Wenchuan earthquake. See Appendix Fig. A3 for detailed geographical descriptions of the placebo designs. The estimated coefficients, reported in Table 4, are close to 0 and statistically insignificant, implying that minor earthquakes have little influence on learning activities and the performance decline of Sichuan students was not caused by other possible shocks across the

[11] Appendix Figure A2 presents all the earthquakes recorded across China in 2009.

Table 5
Sensitivity test.

	(1)	(2)	(3)	(4)	(5)	(6)
	Baseline	Excluding a subgroup of treated counties			Using a smaller control group	
				Wenchuan	Exposed to	Delaying
		Wenchuan	Beichuan	& Beichuan	CSIS VII and VIII	the 2008 NCEE
Earthquake × Post	−0.549***	−0.474***	−0.476***	−0.216**	−0.478***	−0.498***
	(0.128)	(0.156)	(0.144)	(0.090)	(0.142)	(0.134)
Control × Post	Y	Y	Y	Y	Y	Y
County FE	Y	Y	Y	Y	Y	Y
Year-Track FE	Y	Y	Y	Y	Y	Y
Number of counties	179	178	178	177	34	40
Observations	840,320	839,126	838,071	836,877	184,240	161,497
R-squared	0.057	0.057	0.057	0.057	0.084	0.068

Notes: This table reports the sensitivities of earthquake damage on the NCEE standard scores. Column (1) is the baseline results listed for a reference. Columns (2)–(4) exclude Wenchuan and Beichuan one-by-one and simultaneously. Column (5) uses a smaller control group consisting of counties exposed to CSIS VII and VIII. Column (6) uses another smaller control group consisting of counties that delayed the 2008 NCEE. Robust standard errors clustered at the county-year level are in parentheses. * denotes significance at 10%, ** at 5%, and *** at 1%.

country.

4.2.3. Intra-province migration test

A major worry about our research design is the possible intra-province migration. What if some of the younger students affected by the earthquake transferred to other non-affected counties in Sichuan and changed their place of *hukou* registration soon afterwards? In that case, we may overestimate the impact of earthquake damage because advantaged students are more likely to do so and they are also usually more competitive in the NCEE.

To address the concern of intra-province migration, we created a county-level panel data on enrolled secondary school students in Sichuan for pretreatment and treatment years. Appendix Fig. A4 shows descriptive statistics for treated and control counties, respectively. Appendix Fig. A5 also depicts individual trends by treated counties. We saw a similar trend between the two groups, and re-ran a difference-in-differences model to confirm the dynamic changes at county level as follows:

$$Ln(y_{jt}) = \sum_{\tau=2005}^{2011} \beta_\tau Earthquake_j \times Year_\tau + \lambda_j + \gamma_t + \delta_{jt}$$

where y_{jt} is the value of secondary school enrollment in county j in year t; λ_j is the county fixed effect; and γ_t is the year fixed effect. $Earthquake_j \times Year_\tau$ is a set of interactions between the dummy for treated counties and different year periods, where the year 2007 is left as a comparison. By taking logarithms of the dependent variable, we made the data better follow a normal distribution and less affected by extreme values.

As shown in Fig. 3, there is no apparent link between an outmigration of enrolled secondary school students and the earthquake shocks. Moreover, we checked relevant labor force migration using data on secondary school faculties (see Appendix Fig. A5). The results are consistent in both analyses.

We propose two possible reasons for this. First, quake-affected students in most hard-hit areas were indeed forced to transfer to temporary locations with better living and learning conditions, but this was arranged uniformly and officially by local governments. Second, although students in some heavily affected counties were transferred to temporary locations, they were still considered as a collective county-level unit when participating in the NCEE.[12] Therefore, though intra-province migration efforts made by families alone, whether before or after the earthquake occurred, do surely exist to some extent, it should not largely affect our findings.

4.2.4. Sensitivity test

Table 6 explores how the strength of the effect on exam performance would change when excluding a subgroup of treated or control counties. Of all counties in the treated group, Wenchuan and Beichuan suffered the most severe damage. The earthquake's epicenter was located at Yingxiu Town, Wenchuan county; and the civic center of Beichuan even lay in areas with the intensity of CSIS XI. Moreover, the mortality rate in Wenchuan and Beichuan approached or exceeded 10%, significantly higher than in the other two counties. We thus believe that students in these two places should have suffered more severely. Columns (2)–(3) exclude Wenchuan and Beichuan county, respectively; the magnitudes of the impacts decrease to about −0.47. After excluding them simultaneously in Column (4), however, the magnitude of the impact falls by half but remains statistically significant, suggesting that, as expected, Wenchuan and Beichuan contributed the most losses.

Considering that only around 0.5% of the total sample are treated, and the unbalance control-treatment sample might fish results,

[12] For instance, in year 2009, all the grade 12 students from Wenchuan county took part in the exam at Longquanyi district of Chengdu, and this was the unique testing location officially set for them (Li & Zhang, 2009).

Table 6
Using distance to the fault zone as a proxy of earthquake damage.

	(1)	(2)	(3)
	Distance measured as a(n)		
	Continuous variable	Ordinal variable	Dummy variable
Distance × Post	0.002***	0.068***	−0.449***
	(0.001)	(0.023)	(0.143)
Control × Post	Y	Y	Y
County FE	Y	Y	Y
Year-Track FE	Y	Y	Y
Number of counties	179	179	179
Observations	840,320	840,320	840,320
R-squared	0.056	0.056	0.057

Notes: This table reports the using other proxies of earthquake damage. The outcome variable is the NCEE standard score. Each column represents an independent regression. Robust standard errors clustered at the county-year level are in parentheses. * denotes significance at 10%, ** at 5%, and *** at 1%.

Table 7
Using causalities as a proxy of earthquake damage.

	(1)	(2)	(3)
Mortality Rate × Post	−0.051***		
	(0.012)		
(Mortality + Missing) Rate × Post		−0.038***	
		(0.009)	
(Mortality + Missing + Injury) Rate × Post			−0.015***
			(0.003)
Control × Post	Y	Y	Y
County FE	Y	Y	Y
Year-Track FE	Y	Y	Y
Number of counties	179	179	179
Observations	840,320	840,320	840,320
R-squared	0.057	0.057	0.057

Notes: Each column represents an independent regression. The outcome variable is the NCEE standard scores. Columns (2)–(3) replace mortality rate with a combined rate of morality and missing and a combined rate of morality, missing and injury, respectively. Robust standard errors clustered at the county-year level are in parentheses. * denotes significance at 10%, ** at 5%, and *** at 1%.

we perform two robustness checks using a smaller control group. We build the smaller control group in two ways.

First, we define the control sample as the counties located at areas where the intensity was measured at VII and VIII. We find 30 counties located at those areas, close to the treated counties. Second, we define another control sample using the counties which also postponed the NCEE in 2008. A total of 40 quake-stricken counties in Sichuan delayed the NCEE in 2008, including the treated ones. As shown in columns (5)–(6) of Table 5, the magnitudes of the impacts are still close to the baseline result.

4.2.5. Treatment variable redefined

First, following Andrabi and Das (2017) and Andrabi et al. (2021), we exploited variation in the distance from a civic center to the fault line as the conditionally-exogenous measure of the strength of the earthquake shock. The mainshock and aftershocks were distributed along the middle and northeast section of the Longmenshan fault zone.[13] Geologically, Longmenshan is the boundary zone between Tibetan Plateau and Yangtze block. It is mainly composed of three major faults, namely, the front fault (Guanxian-Anxian), the central fault (Yingxiu-Beichuan) and the back fault (Wenchuan-Maoxian), of which the central part is the one that generated the mainshock of the 2008 Wenchuan earthquake. Based on the fault line that runs through those affected areas, we first used a continuous variable to measure the distance between a county's civic center and the fault line; to double check, we created an ordinal variable with four intervals to measure the distance variation, and a dummy variable indicating whether a county's civic center was near the central fault line.[14]

We demonstrate the role of distance to the fault line on the effects of the earthquake in Table 6. Column (1) presents the estimation results using distance as a continuous variable. For each additional kilometer of distance, the standard score increases by 0.23% of a

[13] The Longmenshan fault zone, with a length of over 400 km and width of 30–50 km, stretches from southern Luding county to Qingchuan county in the north.

[14] Four intervals were used to set the distance range between the central fault line and a county: $<$10 km, $\geq$ 10 and $<$ 20 km; $\geq$ 20 and $<$ 40 km, and $\geq$40 km. The dummy variable takes the value of 1 if a county's civic center was located within 10 km of the central fault line and 0 otherwise, and four counties were identified below the threshold of 10 km: Wenchuan, Qingchuan, Baoxing, and Luding.

Table 8
Results for science and liberal arts tracks.

	(1) Science track	(2) Liberal arts track
Earthquake × Post	−0.517***	−0.560***
	(0.120)	(0.173)
Control × Post	Y	Y
County FE	Y	Y
Year-Track FE	Y	Y
Number of counties	179	179
Observations	604,719	235,601
R-squared	0.060	0.061

Notes: The outcome variable is the NCEE standard score. Standard errors in parentheses are clustered at the county-year level. * denotes significance at 10%, ** at 5%, and *** at 1%.

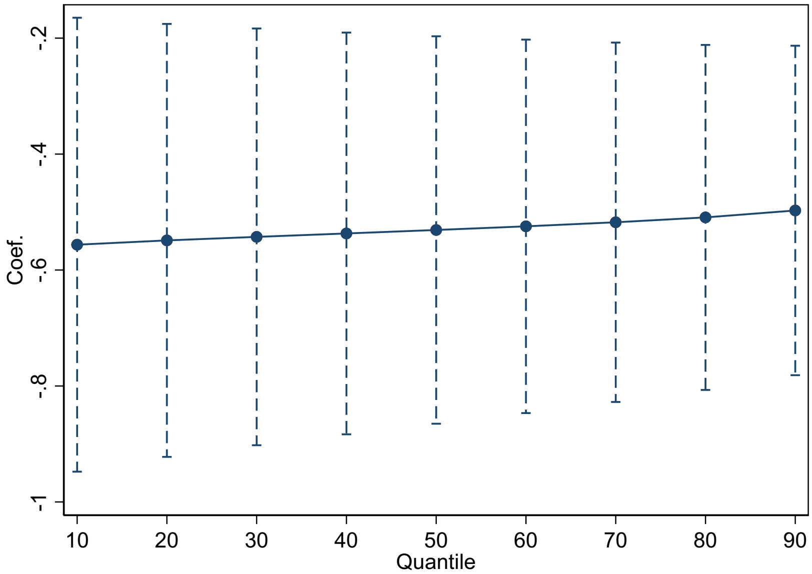

Fig. 4. Effects of earthquake damage on the NCEE standard scores by decile.
Notes: Estimates of the earthquake damage's impact on changes in NCEE standard scores are plotted in the solid connected line. The dashed error bars represent the 95% confidence intervals with standard errors computed using bootstrap methods that preserve the clustered structure of the data. All regressions include the control variables reported in Column (2) of Table 3, and the county and year-track fixed effects.

standard deviation. Column (2) demonstrates a consistent finding when cutting the distance into four scales. As shown in column (3), our results are again robust to using a dummy variable instead of the one-to-four scale. Being located near the fault line led to a 45% standard deviation decrease in test scores, a bit smaller than that of earthquake intensity method.

Second, we used casualties as proxies for the variable of interest. According to RGWERE project, the earthquake killed nearly 70,000 people, and injured >370,000. At least 18,000 individuals remain missing (see Appendix Table A2). As shown in Table 7, we found that a 1% increase in mortality rate was associated with a 5.1% standard deviation decrease in NCEE standard scores in that county. The results are robust to including a boarder measure of casualties. The effects would be, however, largely leveraged by counties with a high rate of mortality such as Wenchuan and Beichuan. Also notice that casualties are likely to be endogenous because the data partly reflect the capacity of local governments, which will in turn impact the delivery of public education services and children's academic achievements. We therefore showed their results just for reference purposes.

4.3. Heterogeneity

In this section, we explore potential heterogeneity across major tracks and individuals.

4.3.1. Sample divided by tracks

As noted earlier, the NCEE has two independent tracks (science and liberal arts), each of which has its own test papers, grading procedures, and admission thresholds. High school students usually choose a specific track at the end of Grade 10, about two years

Table 9
Channels through which the earthquake affects academic performance: a county-level analysis.

	(1)	(2)	(3)	(4)	(5)	(6)
	Infrastructure		Economy		Medical services	
	Electricity Consumed in Rural Areas (10,000 kilowatt hour)	Total Agricultural Machinery Power (10,000 kilowatt)	Gross Value of Industrial Output (100 million yuan)	GDP per capita (1000 yuan)	# of Hospitals	# of Hospital Beds
Earthquake × Post	−730.904***	−2.042**	−70.733***	−4.354***	−1.701***	−377.818***
	(219.563)	(0.853)	(7.934)	(1.001)	(0.603)	(51.425)
County FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Observations	1239	1211	1201	1239	1238	1236
R-squared	0.902	0.956	0.780	0.893	0.916	0.957

Notes: Each column represents a separate regression. The sample period is from 2005 to 2011. Columns (1)–(2) estimate the impact of the earthquake on infrastructure in terms of electricity consumed in rural areas and total agricultural machinery power. Columns (3)–(4) estimate the impact of the earthquake on the local economy in terms of the gross value of industrial output and GDP per capita. Columns (5)–(6) estimate the impact of the earthquake on medical care in terms of the number of hospitals and hospital beds. Robust standard errors in parentheses are clustered at the county level. * denotes significance at 10%, ** at 5%, and *** at 1%.

before participating in the NCEE. In Table 8, we split the sample by tracks and present estimates for the science track and the liberal arts track, respectively. Notice that we replaced the year-track fixed effects with year fixed effects only. The results show that the earthquake's negative effects were reflected in both tracks. It should be noted that it is up to students to choose between the science and liberal arts track. Students with learning difficulties (e.g. math anxiety) are more likely to prefer to choose the liberal arts track, a phenomenon especially remarkable among minority students; the achievement gaps thus might further be widened after their conditions deteriorated.

4.3.2. Quantile regressions

To reveal a finer-grained effect of earthquake damage, we adopted quantile regression estimation. This regression is important for two reasons. First, since the earthquake was likely to have different effects on students, estimates might conceal a degree of heterogeneity in students' responses to the damage. Second, since we only observed exam takers that were ultimately admitted to a college, sample selection could result from negative effects concentrated at the bottom of the ability distribution. Fig. 4 shows that the results largely point to a monotonically increasing linear trend by decile of the NCEE standard score, with declines in test performance occurring across a broad range of students. One caveat is that the effects become larger near the lower end of the distribution, implying that we may be underestimating the impact of earthquake damage on exam performance due to the truncated sample. If there was a higher proportion of students who simply failed or gave up on the NCEE in quake-affected counties, then our estimate would be an upper bound of the true performance decline.

4.4. Mechanisms

Natural disasters are complex phenomena that may affect academic achievement through many channels. Due to data limitations, it is beyond the scope of this paper to reveal every individual path through which the disaster could have decreased students' test performance over the post-earthquake period studied. It is worth noting that for any factor to account for our main results, it would need to satisfy two criteria: (1) its effect is correlated with earthquake damage; (2) its effect changed discontinuously before and after the seismic event. We posit that the specific mechanisms by which the Wenchuan earthquake impacted NCEE scores were related to local infrastructure, economy, and accessibility to medical services.

We constructed a panel data set of 179 counties in Sichuan from 2005 to 2011 to test the hypotheses proposed. Columns (1)–(2) of Table 9 present the impact on local infrastructure, including electricity consumed in rural areas and total consumption of agricultural machinery power. Results suggest that compared with the control group, the infrastructure damage in the treated counties was more serious. Columns (3)–(4) report the results focusing on the local economy. When examining the correlation between earthquake damage and economic development, we found that earthquake exposure was associated with a 4354 yuan (USD 691) decrease of GDP per capita, about 18% of the average GDP per head in 2011. The results reported in column (5)–(6) also suggest that the number of hospitals and hospital beds had significantly decreased in severely damaged counties within 4 years after the earthquake. Overall, the results show that the earthquake created massive distortions in the damaged regions.

5. Discussion of further consequences

The consequences of earthquake damage extend beyond a decline in test performance. Having verified the linkage between increased exposure to damage and decreased performance in a high-stakes test, it follows that declining academic outcomes would

Table 10
The impact of earthquake damage on enrollment in elite colleges.

	(1)	(2)	(3)	(4)
	Enrolled in a project 211 college		Eligible to apply for a first-tier college	
	Baseline	Dynamics	Baseline	Dynamics
Earthquake × Post	−0.074***		−0.123***	
	(0.012)		(0.023)	
Earthquake × 2005		−0.003		0.024
		(0.023)		(0.019)
Earthquake × 2006		0.021		0.033
		(0.017)		(0.025)
Earthquake × 2008		−0.076***		−0.056**
		(0.023)		(0.024)
Earthquake × 2009		−0.056***		−0.051**
		(0.016)		(0.021)
Earthquake × 2010		−0.0657***		−0.154***
		(0.014)		(0.032)
Earthquake × 2011		−0.075***		−0.160***
		(0.013)		(0.023)
Control × Post	Y	Y	Y	Y
County FE	Y	Y	Y	Y
Year-Track FE	Y	Y	Y	Y
Number of counties	144	144	144	144
Observations	683,104	683,104	683,104	683,104
R-squared	0.051	0.051	0.076	0.076

Notes: The outcome variable are dummies, indicating whether a student is enrolled in a Project 211 college and is eligible to apply for a first-tier college, respectively. Standard errors in parentheses are clustered at the county-year level. * denotes significance at 10%, ** at 5%, and *** at 1%.

relate to further welfare losses. In this section, we extend the analysis to quantify the impacts of the Wenchuan earthquake on college and major choices, and on relocation to developed cities for higher education.

5.1. Does the quality of institutions attended decrease?

China's higher education system is highly stratified, with 112 universities belonging to Project 211—the most elite designation in the nation.[15] These universities have received substantial financial support from the central government, have invested heavily in scientific research and talent training, and have become increasingly popular since the early 2000s. Traditionally, universities are also divided into four tiers: the first tier consists of central universities and some of the provincial key colleges, and those in lower tiers are often perceived as inferior to the selective first-tier colleges. Access to higher education, especially elite higher education, is heralded as among the most important channels for social mobility in modern societies (Jia & Li, 2021; Li, Meng, Shi, & Wu, 2012; Zimmerman, 2019). In light of the great weight placed on exam scores in college admission processes, it is worth knowing whether earthquake-affected students are forced out of elite universities.

To test this hypothesis, we constructed a dummy variable indicating whether or not a student was admitted to a Project 211 university. We also supplemented the NCEE dataset with data on cut-off scores by year and track that determine admission eligibility to first-tier universities, and constructed a dummy variable for eligibility to apply for a first-tier university.[16] Note that the chance of admission for students in less affected counties will also be affected by the earthquake. We defined a county as a less affected one if it had postponed the NCEE in 2008, except for the treated counties already noted. We dropped the less affected counties from the control group for the admission results. Given the admission quota for Sichuan province, if the earthquake reduces the chance of admission for students in the affected counties, it will inevitably increase the chance for those in the unaffected counties. Therefore, instead of describing the admission results as causal, we interpreted them as descriptive evidence of an enlarged gap between affected and unaffected areas.[17]

We re-estimated both the baseline and dynamic regressions. As shown in Table 10, the earthquake reduced opportunities to attend elite colleges. Compared with candidates from non-disaster areas, the probability of candidates from disaster areas going to a project 211 college dropped by about 7.4% after the earthquake, and the probability of candidates from disaster areas going to a first-tier college dropped by about 12.3%. From the perspective of dynamic effects, this disparity also began to appear after the earthquake. We found that the probability of entering first-tier colleges fell further after 2009, which is consistent with previous results that the impact of earthquakes persisted for a long time and had a greater impact on test takers in 2010 and 2011.

[15] Project 211 started in 1995 and intended to create 100 globally competitive research universities in China in the twenty-first century(Yang & Wang, 2020).
[16] The data involving year-track specific thresholds are obtained from a website specialized for the NCEE: http://www.gaokao.com/
[17] We thank one of our anonymous reviewers for his/her helpful suggestions.

Table 11
The impact of earthquake damage on enrollment in high-paying majors.

	(1)	(2)	(3)	(4)	(5)	(6)
	Economics/Finance		Architecture		Computer science	
	Eligible to apply for a first-tier college					
	Yes	No	Yes	No	Yes	No
Earthquake × Post	0.565**	1.316	0.114**	1.189	0.741	1.145
	(0.148)	(0.233)	(0.117)	(1.078)	(0.268)	(0.190)
Control × Post	Y					
County FE	Y					
Year-Track FE	Y					
# of counties	144					
Observations	683,104					
Log pseudolikelihood	−278,382.1					

Notes: The Mlogit analysis uses other majors as the reference group. Standard errors in parentheses are clustered at the county-year level. * denotes significance at 10%, ** at 5%, and *** at 1%.

5.2. *Are affected students forced out of majors in high-salary fields?*

We demonstrated that earthquake exposure reduces the enrollment rate in elite colleges for students in the affected regions, and a question that naturally follows is: are these students also forced out of majors that prepare them for professions with high salaries? In this subsection, we answer this question by examining major choices.

According to the "Chinese College Students Employment Report" by the MyCOS Institute, economics, finance, architecture, computer science, etc. were all high-paying majors in 2012.[18] We set the variable into four categories: economics/finance, architecture, computer science, and others. Since students are likely to make trade-offs between universities and majors, we further combine colleges and majors to examine student choices. We expect that due to the impact of the earthquake, students in disaster areas will likely not be able to enter high-paying majors at elite universities; however, this effect does not necessarily exist at non-elite universities. They are unordered choices over multiple categories, so we used a multinomial logistic model embedded in the difference-in-differences setup described in the main analysis.

Results presented in Table 11 seem to show a trade-off between colleges and majors in high-paying fields. We see a decrease in the enrollment for high-paying majors (e.g., economics/finance) in the subgroup of candidates eligible to apply for a first-tier university, but these effects do not exist for those attending non-elite colleges. This trade-off reflects in part the increased likelihood of pursuing higher education, but also the pursuit of popular majors at the cost of college quality.

5.3. *Where do affected students receive their higher education?*

In addition to college quality and major choice, the location of a college is an important consideration when applying. Compared with small and remote cities, large cities offer a more attractive prospect for college students, with more internship, job, and entrepreneurial opportunities. Along with the "squeeze-out" effects identified above, we scrutinized a possible similar effect in terms of geographical advantage. Specifically, we examined whether quake-affected students were less likely to go to a college located in Beijing or Shanghai, Chengdu, and other major cities,[19] but more likely to go to a college in an under-developed province.[20] Since it is also an unordered categorical variable, we used the multinomial logistical regression for analysis.

Considering that some survivors may fear a future catastrophe, we were interested in exploring a potential "escaping" tendency caused by the earthquake. First, we simply created a dummy variable, coded as 1 if the college attended was outside of Sichuan. Second, we calculated the geographical distance between the location of the student's hometown and the college attended using GIS techniques provided by Gaode map.[21] We hypothesized that earthquake damage might produce a larger effect on the distance that students were looking to travel.

[18] It should be noted that the high salary here refers to the average monthly income of graduates within half a year after graduation.

[19] We define 19 cities as other major cities in China, including Tianjin, Chongqing, Guangzhou, Shenzhen, Ningbo, Qingdao, Dalian, Xiamen, Harbin, Changchun, Shenyang, Jinan, Nanjing, Hangzhou, Wuhan, Xian, Fuzhou, Changsha, and Hefei. We pick them out in that they are developed municipalities, provincial capitals, or vice-provincial cities.

[20] We define 12 provinces as under-developed provinces in China, including Guangxi, Guizhou, Yunnan, Qinghai, Ningxia, Xinjiang, Tibet, Inner Mongolia, Henan, Jiangxi, Shanxi, and Hebei. We pick them out for two reasons. First, they are economically underdeveloped relative to the eastern coastal provinces and cities. Second, there are no Project 985 universities in these provinces, making them less attractive in terms of higher education opportunities.

[21] Gaode, comparable to Google outside of China, provides users with a wide range of web services. Geocoding, the tool exploited here, is a process of converting a location into a pair of geographic coordinates (latitude/longitude) that are used to evaluate distances. A civic center is linked to a location and thus could be geocoded to a latitude/longitude coordinate. Using the Haversine formula (Robusto, 1957), the distance between two coordinates can be calculated with ease.

Table 12
The impact of earthquake damage on regions where students attended higher education.

	(1)	(2)	(3)	(4)	(5)	(6)
	Mlogit				OLS	
	Regions				Travel distance	
	Beijing or Shanghai	Chengdu	19 major cities	Under-developed	Whether in Sichuan	Geographic distance
Earthquake × Post	0.613***	0.955	0.980	1.664***	−0.015	32.469
	(0.112)	(0.096)	(0.216)	(0.297)	(0.033)	(31.000)
Control × Post	Y				Y	Y
County FE	Y				Y	Y
Year-Track FE	Y				Y	Y
# of counties	144				144	144
Observations	683,104				683,104	683,104
Log pseudolikelihood	−862,199.56					
R-squared					0.024	0.030

Notes: The Mlogit analysis uses other cities as the reference group. In columns (1)–(4), the outcome variable is a categorical variable that denotes the city or region a test take goes to. In column (5), the outcome variable is a dummy indicating whether a student goes to a university out of Sichuan. In column (6), the geographical distance is defined as the distance between the location of a student's hometown and the location of the college he/she attended. Robust standard errors in parentheses are clustered at the county-year level. * denotes significance at 10%, ** at 5%, and *** at 1%.

Results are presented in Table 12. Quake-affected students were more likely to be crowded out of prosperous cities like Beijing and Shanghai (where also exist many highly ranked universities), relocating instead to under-developed regions. Also, we found no evidence that students who suffered more severely from the earthquake tended to move farther away from their hometowns. This is likely because a college's reputation plays a decisive role in choosing it as a destination for higher education.

6. Conclusions

This study investigated the impact of a devastating natural disaster on students' performance on a high-stakes exam in China. Results suggest that a high degree of exposure to earthquake led to a 0.55 standard deviation decrease in NCEE scores. Estimates of dynamic effects show that the magnitudes of the impacts were − 0.11 for cohorts in 2008 and 2009 and around −0.83 for cohorts in 2010 and 2011, which suggests that the negative shocks mainly affected those exposed to the damage for a longer duration. Models from a series of robustness checks generated quantitatively similar estimates, supporting the causal interpretation of our findings.

We conclude that the impacts of earthquake damage are heterogeneous. For our sample, the effect was slightly greater for students who majored in the liberal arts track (relative to the science track), and the effect was greater for exam takers with low performance rankings. It also seems that high-achieving students can mitigate the damaging effects of damage exposure.

The significant decline in test performance has broader implications. Exploiting the type of college attended, we showed how earthquake damage caused students to be squeezed out of high-ranking universities such as Project 211 colleges. Moreover, among the subgroup of students admitted to elite colleges, quake-affected students were less likely to enroll in high-paying majors. Finally, we found a similar "squeeze-out" effect in terms of geographical preferences: affected students were forced out of major cities such as Beijing and Shanghai, relocating instead to under-developed provinces.

Overall, these findings highlight the human capital costs of natural disasters. As one of the first papers to evaluate the association between earthquake exposure and high-stakes examination performance, this study confirms that in addition to heat waves, air pollution and pollen inhalation, natural disasters such as severe earthquakes can also cause major setbacks on performance in a high-stakes setting. The earthquake exposure not only reduces a test-taker's cognitive ability measured by nationwide standardized testing scores, but also compromises one's college quality in terms of access to first-tier universities, majors with high premiums, and campus in metropolitans. The double losses in both quantity and quality of accumulated human capital related to the earthquake exposure provide a clear-cut explanation for the observed declining educational attainment in disaster-affected regions. In other words, this study opens the black box on how the negative shocks affect human capital accumulation in developing economies with massive population: the long-term human capital gaps in the disaster- affected regions are due to the substantial reduction in aggregate cognitive performance measured by standardized testing and the denial of access to high-quality education opportunities in later life stages.

The case of Wenchuan earthquake, like its counterparts in China (Wang et al., 2017) and in Latin American countries (Caruso, 2017; Caruso & Miller, 2015; Luzincourt & Gulbrandson, 2010) also calls for more effective and sustainable rescue efforts. Given the short- and long-term human capital deficits related to natural disasters, it is critical to reconsider how to integrate educational relief into broader humanitarian coordination after crises. Reconstructing educational capacity of local communities with sustainable development strategies in a timely manner is thus equally, if it is not more, important than restoration of the basic physical infrastructures and the economy.

Due to data limitations, we were unable to observe the possible effects on test performance four years after the earthquake hit. Presumably, accumulated exposure to the aftermath of natural disaster would lead to increasingly negative impacts for cohorts who had just entered primary school relative to those nearly completing high school education. Future research is warranted to better understand the quake's long-term damaging effects, which can be useful for informing targeted and sustainable aid policies.

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Appendix

Table A1
China seismic intensity scale (CSIS).

	Senses by people on the ground	Degree of building damage	PGA (m/s^2)	Peak speed (m/s)
I	Insensible			
II	Sensible by very few still indoor people			
III	Sensible by a few still indoor people	Slight rattle of doors and windows		
IV	Sensible by most people indoors, a few people outdoors; a few wake up from sleep	Rattle of doors and windows		
V	Commonly sensible by people indoors, sensible by most people outdoors; most wake up from sleep	Noise from vibration of doors, windows, and building frames; falling of dusts, small cracks in plasters, falling of some roof tiles, bricks falling from a few roof-top chimneys	0.31 (0.22–0.44)	0.03 (0.02–0.04)
VI	Most unable to stand stably, a few scared to running outdoors	Damages - Cracks in the walls, falling of roof tiles, some roof-top chimneys crack or fall apart	0.63 (0.45–0.89)	0.06 (0.05–0.09)
VII	Majority scared to running outdoors, sensible by bicycle riders and people in moving motor vehicles	Slight destruction - localized destruction, crack, may continue to be used with small repairs or without repair	1.25 (0.90–1.77)	0.13 (0.10–0.18)
VIII	Most swing about, difficult to walk	Moderate destruction - structural destruction occurs, continued usage requires repair	2.50 (1.78–3.53)	0.25 (0.19–0.35)
IX	Moving people fall	Severe destruction - severe structural destruction, localized collapse, difficult to repair	5.00 (3.54–7.07)	0.50 (0.36–0.71)
X	Bicycle riders may fall; people in unstable state may fall away; sense of being thrown up	Most collapse	10.00 (7.08–14.14)	1.00 (0.72–1.41)
XI		Widespread collapse		
XII				

Notes: The China seismic intensity scale (CSIS) is a national standard in China used to measure seismic intensity, published by Administration of Quality Supervision, Inspection, and Quarantine of P.R.C. The standard was initially formalized in 1980 and revised later in 1999, not long before the 2008 Wenchuan earthquake.

Table A2
Summary statistics of earthquake casualties recorded in ten worst affected counties.

County	# of Deaths	# of Missing people	# of Injured people	Mortality rate	Population (in thousands)
Wenchuan	15,941	7595	34,583	14.26%	111.8
Beichuan	15,646	4932	26,916	9.90%	158.0
Mao	4016	0	8183	4.41%	91.1
Mianchu	11,117	251	37,209	2.18%	510.0
Qingchuan	4697	124	15,453	1.88%	250.0
Pingwu	3014	3551	32,145	1.62%	186.1
Shifang	5924	198	33,075	1.38%	430.0
Anxian	2640	655	13,476	0.53%	500.0
Dujianyan	3091	192	10,560	0.52%	600.0
Pengzhou	952	147	5775	0.12%	794.7

Notes: Treated counties, 4 out of the top 5 worst affected regions, are denoted in bold and italics; and their civic centers were located in areas measured at intensity CSIS IX or higher.
Source: The RGWERE dataset.

Table A3
Summary statistics on county-level characteristics.

Variable	(1) Mean (S.D.)	(2) Data source
Pre-determined characteristics (N = 179)		
GDP per capita in 2005 (one thousand yuan)	8.93 (6.71)	2005 Sichuan Statistical Yearbook

(*continued on next page*)

Table A3 (*continued*)

	(1)	(2)
Variable	Mean (S.D.)	Data source
% of people with agricultural hukou status	77.6% (0.20)	2005 Sichuan Statistical Yearbook
State-designated elite high school (yes =1)	27.9% (0.45)	China Education and Research Network
# of enrolled secondary school students in 2005	26,388.8 (23,148.5)	2005 Sichuan Statistical Yearbook
Average elevation of the civic center (meter)	799.75 (772.12)	Google earth
Time-varying characteristics (N = 1267)		
# of enrolled secondary school students	26,974.5 (22,728.7)	Sichuan Statistical Yearbooks (2005–2011)
# of secondary school faculty members	1518.3 (1206.9)	Sichuan Statistical Yearbooks (2005–2011)

Notes: Pre-determined characteristics are cross-sectional data determined before 2008.

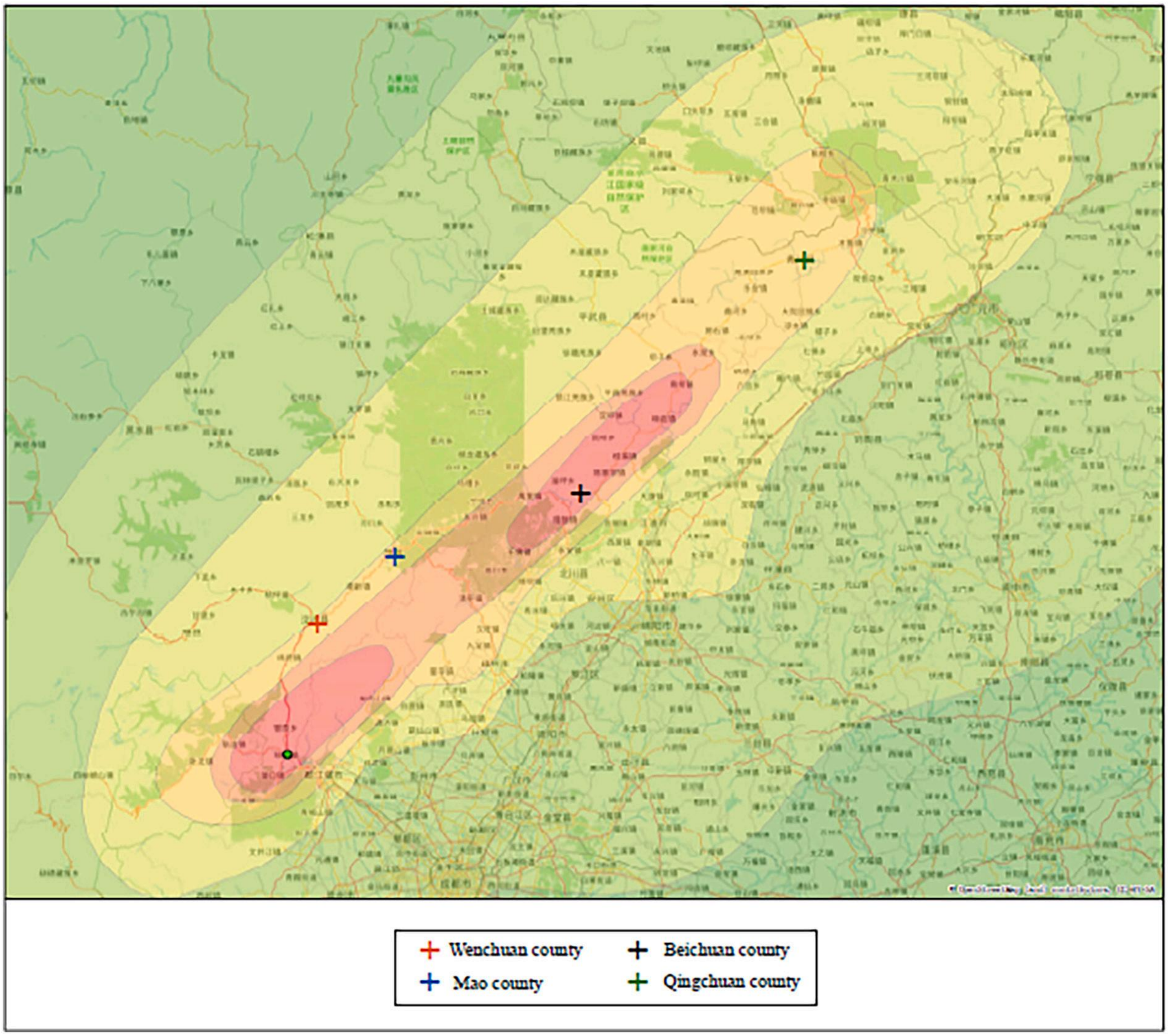

Fig. A1. Locations of treated counties.

Notes: Counties whose civic center was subject to intensities measured at or above IX is defined as the treated group. In that case, four counties were identified (i.e., Wenchuan, Mao, Beichuan, and Qingchuan). The location of each county-level civic center is denoted using a colored cross, respectively. Notice that the civic center of Beichuan has been relocated southwardly due to the devastation caused by the earthquake, and we therefore refer to the original civic center in the graph.

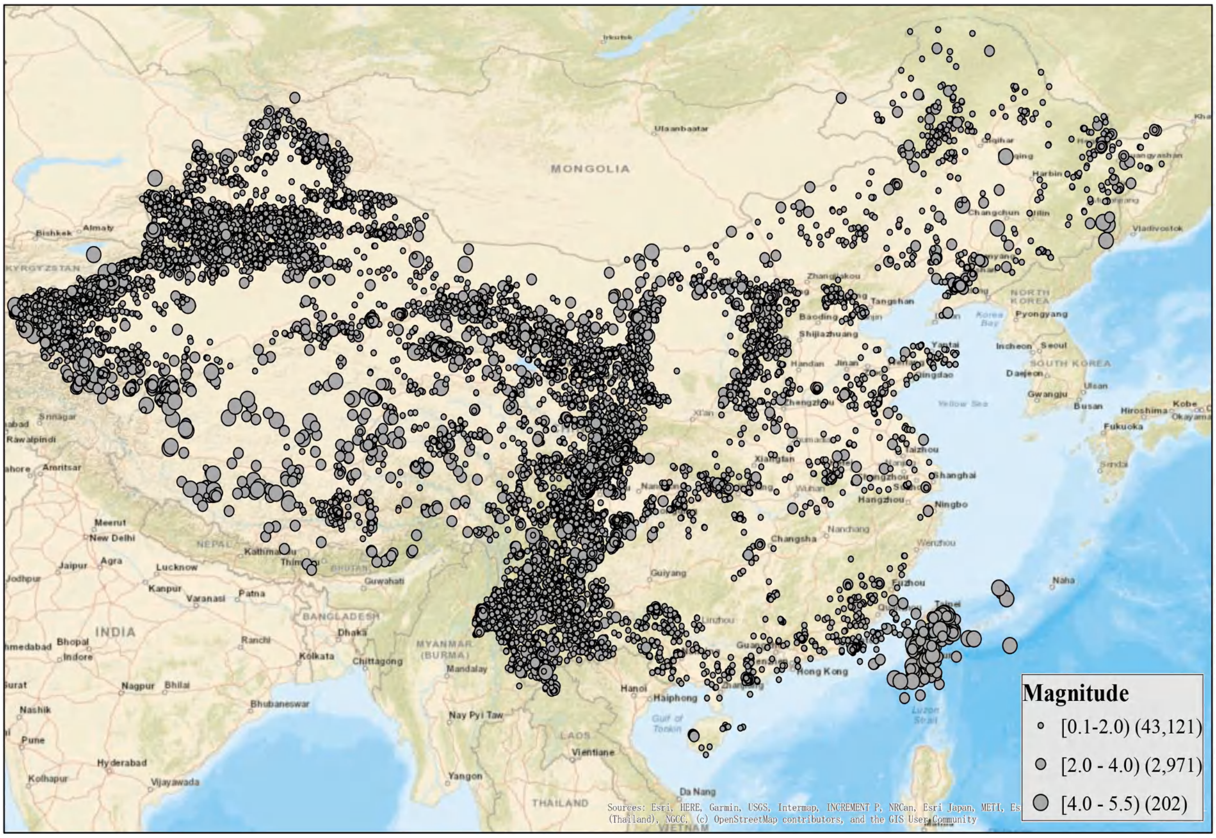

Fig. A2. Distribution of the earthquakes recorded across China in 2009.

Notes: This figure depicts all the earthquakes recorded across China in 2009.
Data source: China Earthquake Networks Center.

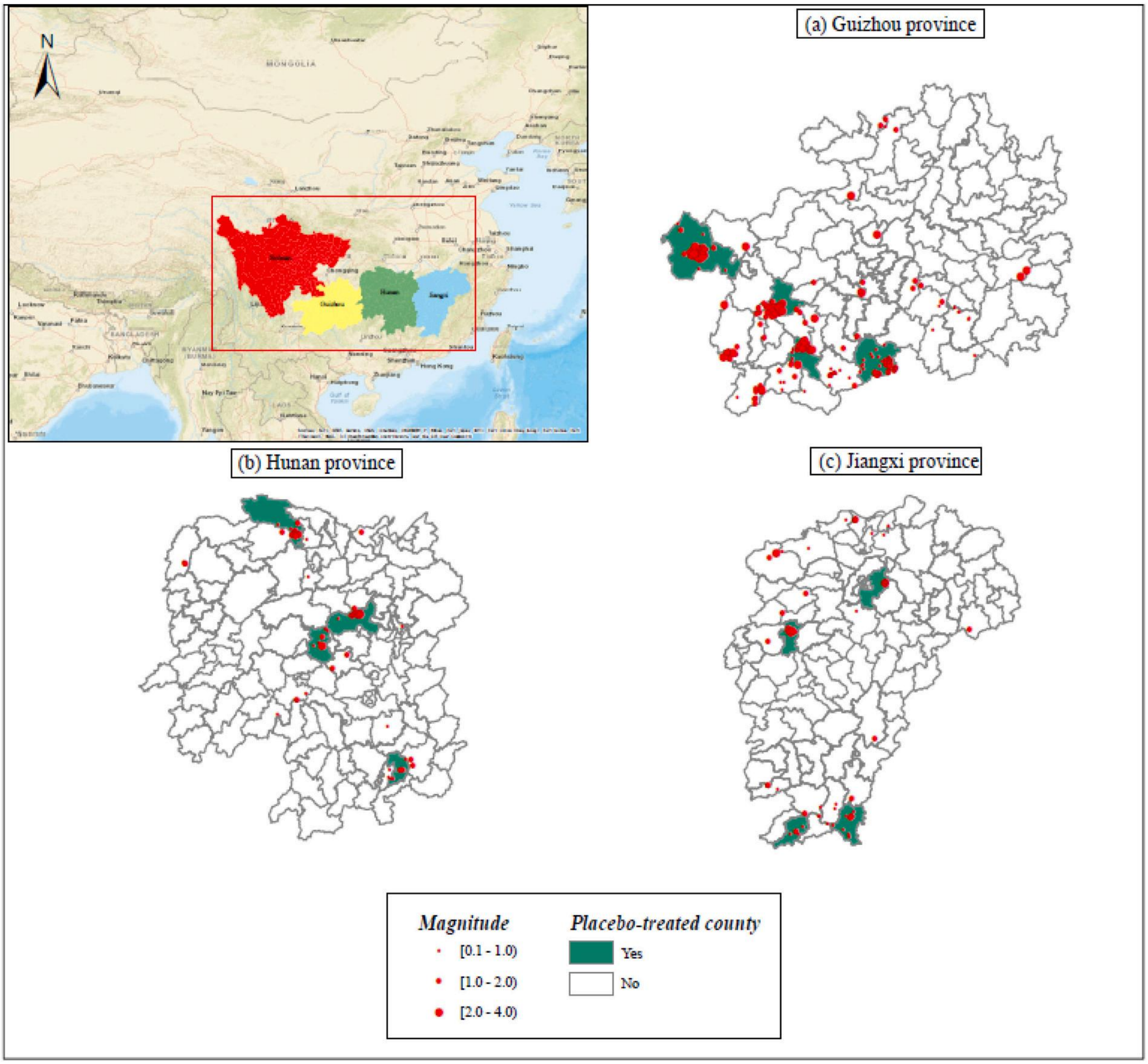

Fig. A3. Simulated treated counties designated by weak earthquakes across Guizhou, Hunan, and Jiangxi Province.
Notes: Placebo-treated counties were selected based on the number of weak earthquakes (the top four in each province) recorded in 2009. Data source: China Earthquake Networks Center.

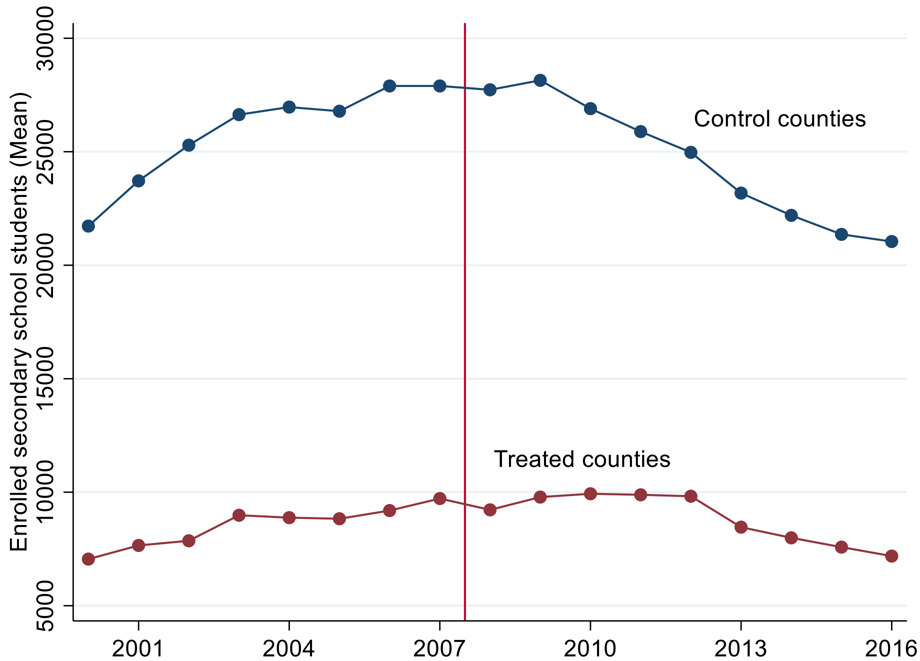

Fig. A4. Secondary School Enrollment between Treated and Control Counties (2000–2016).
Notes: This figure depicts the mean values of enrolled secondary school students in pre- and post-treatment periods.

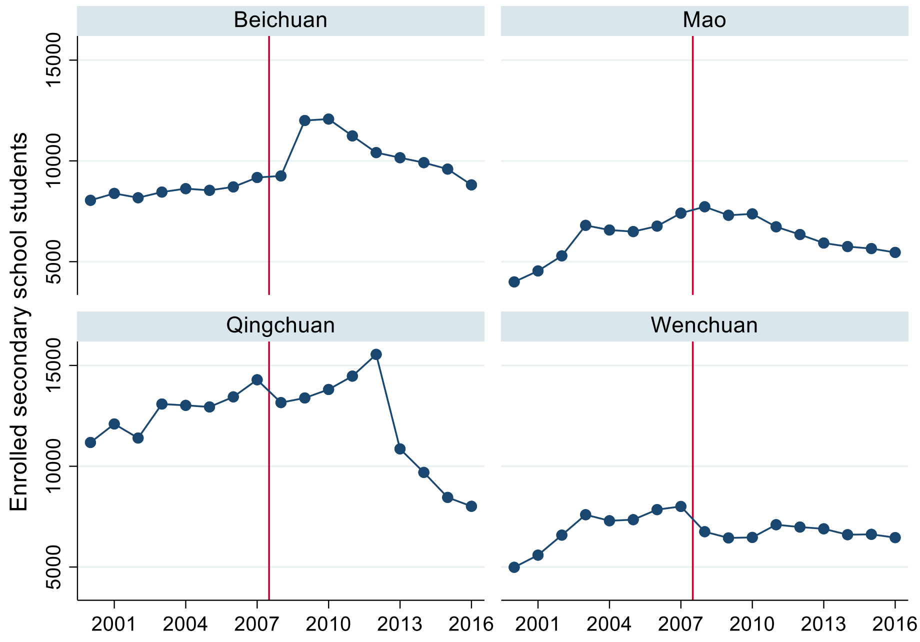

Fig. A5. Secondary school enrollment in treated counties (2000–2016).
Notes: This figure depicts the numbers of enrolled secondary school students by treated counties.

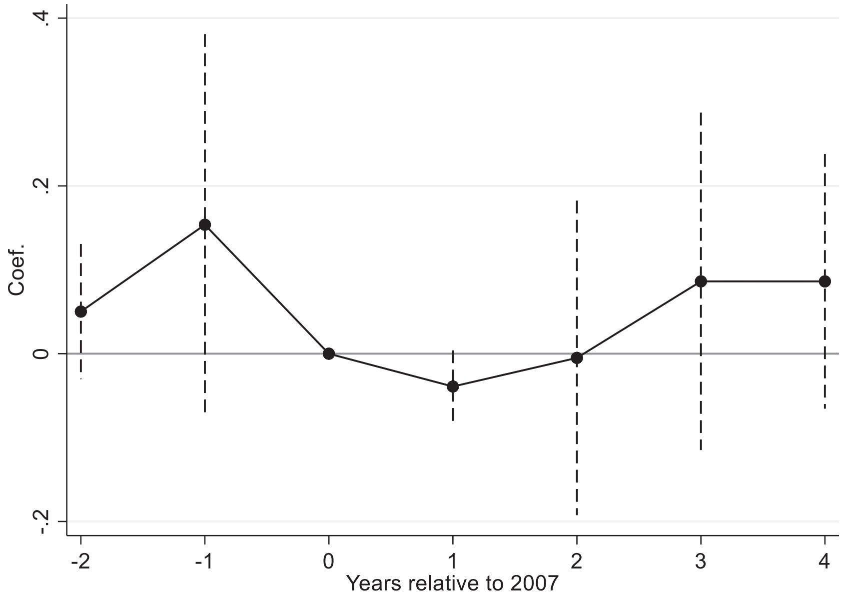

Fig. A6. Intra-province migration test using data on secondary school teachers.
Notes: This graph visualizes the dynamic effects of earthquake damage on enrolled secondary school teachers, using the year 2007 as the reference, where the solid lines connect the estimates and the dashed lines indicate the 95% confidence intervals.

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