Journal of Happiness Studies
https://doi.org/10.1007/s10902-022-00609-z

RESEARCH PAPER

Well-being Effects of Natural Disasters: Evidence from China's Wenchuan Earthquake

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Accepted: 30 November 2022

Abstract

This study finds that the Wenchuan earthquake in 2008, one of China's most catastrophic earthquakes, substantially decreased victims' subjective well-being even after incorporating the offsetting effects of post-disaster relief programs. This net well-being impact lasted for nearly 10 years and was on average equivalent to a loss of 67% of the average equivalized household income. Although the post-disaster measures largely restored income, health, and employment, they failed to prevent well-being losses due to family dissolution, as reflected in the higher rates of divorce and widowhood after the earthquake. We find that rural populations, older adults, the less educated, and residents without social insurance were more vulnerable to the earthquake shock. This study uses six waves of a nationally representative dataset of China and a difference-in-differences approach to identify the short- and long-term causal well-being effects of the Wenchuan earthquake. Deeper analyses on mechanisms and heterogeneity suggest that post-disaster policies should focus more on aspects beyond economic factors and on the well-being of disadvantaged populations in particular.

Keywords Subjective well-being · Natural disasters · Wenchuan earthquake · Difference-in-differences

1 Introduction

Natural disasters, including meteorological, geological, and biological disasters, often induce threats to economic development (Gignoux & Menéndez, 2016; Strobl, 2012), human capital (Caruso, 2017; Caruso & Miller, 2015), and subjective well-being (SWB; Carroll et al., 2009; Luechinger & Raschky, 2009). The well-being cost of natural disasters could even be comparable to the financial losses caused by disasters (Carroll et al., 2009; Luechinger & Raschky, 2009; Ohtake, et al., 2016; Rehdanz et al., 2015). This study quantifies the well-being effect of the 2008 Wenchuan earthquake, China's most devastating

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Published online: 11 December 2022

natural disaster in decades, and deciphers the mechanisms through which the disaster impacted victims' well-being. This study's findings can help policymakers evaluate the welfare losses associated with natural disasters and develop targeted measures to mitigate damage to public well-being, particularly in the developing world, where disasters may be more destructive and disaster relief is relatively insufficient.

A branch of research has focused on the well-being impact of natural disasters, such as droughts (Carroll et al., 2009), floods (Luechinger & Raschky, 2009), and hurricanes (Kimball et al., 2006; LaJoie et al., 2010). People facing these disasters could be prepared based on available forecasts and seasonal experience, or may have enough time to conduct urgent adjustments (Berlemann, 2016). In contrast, an earthquake shock is unpredictable and random, and may lead to greater hardship. Some studies have focused on Japan, where earthquakes occur frequently. Yamamura (2012) examines changes in victims' SWB over time after the 1995 Hanshin-Awaji earthquake. Rehdanz et al. (2015) estimate the loss in SWB caused by the 2011 Fukushima disaster, which included an earthquake, a tsunami, and a nuclear accident. A few studies examine the short-term impact of the Wenchuan earthquake on well-being. Xin et al. (2009) and Tao et al. (2009) assess local victims' SWB 1 to 3 months after the Wenchuan earthquake. Li et al. (2009) measure the SWB of local residents periodically in the 4th, 6th and 8th month after the Wenchuan earthquake. All the studies confirm the considerable negative effects of earthquakes on SWB, at least in the short term.

Studies usually track victims' SWB over time (Li et al., 2009; Tao et al., 2009; Xin et al., 2009) or compare victims and non-victims' SWB at a certain point in time (Yamamura, 2012) to estimate the well-being effect of earthquakes. Despite the randomness of earthquakes, the time-series change or cross-sectional comparison of SWB may have generated biased estimates. On the one hand, temporal changes in victims' SWB may have resulted from sources other than earthquakes. On the other hand, people choosing to reside in an earthquake-prone region may have different SWB-related characteristics from those living in other areas. Rehdanz et al. (2015) handle this issue by using a difference-in-differences (DID) strategy to identify the causal effects of the 2011 Fukushima disaster on SWB based on variations in pre- and post-disaster data and distance from the epicenter. As their dataset contains only one wave before the disaster, the critical parallel-trend assumption of DID is not formally tested.

A mechanism analysis is crucial as it could enrich our understanding of the channels through which disasters impact well-being and direct policymakers to take effective preventive and remedial measures toward disasters; however, the literature contains very few analyses and discussions on the mechanisms. Carroll et al. (2009) indirectly conclude that an Australian drought may affect SWB through agricultural production and related economic factors because only a spring drought has a significant impact on the SWB of rural residents. By comparing the results with potential channel variables being controlled to those not being controlled, Rehdanz et al. (2015) indirectly infer that disasters do not seem to affect SWB through health, income, or employment.

To fill these gaps in the literature, our study makes two contributions. First, we employ a DID approach to identify the causal effects of the Wenchuan earthquake on SWB. This approach is widely used to estimate the impact of a shock that affects some people over a period of time but not others. The causal effect can be estimated by specifying the multiple dimensions of the shock, provided that SWB in the affected areas shares the same trend as SWB in the unaffected areas had the shock never happened. One dimension of the DID strategy is timing—before versus after the year of the earthquake (2008); the other dimension is location—unaffected provinces versus Sichuan province, that is, the location of the earthquake's epicenter in Wenchuan county. The strategy is implemented with a pooled individual-level cross-sectional dataset that is nationally representative and covers two waves before the earthquake and four waves after the earthquake in 2008. The rich dataset allows us to test the parallel-trend assumption formally and explore the long-run well-being effect, which has been largely ignored by other studies on the Wenchuan earthquake. Next, we delve into a concrete mechanism analysis. Following the paradigm of Cantril (1965) and Easterlin (2010), we investigate five likely channels through which disasters impact SWB, including income, health, family, jobs, and social capital.

We find that, compared to residents in the unaffected areas, Sichuan residents, specifically rural populations, have experienced a significant decline in SWB since the Wenchuan earthquake and that this negative effect was maintained for nearly 10 years. The quantified compensation variation of well-being loss is 67% of the average equivalized household income—similar to the amount estimated in the Fukushima earthquake. Regarding the mechanisms, economic status (income and jobs) and physical health may not play critical roles, probably due to the offsetting effect of the post-disaster relief and recovery plans. Family destruction caused by the earthquake, which cannot be mitigated through outside help, appears to be a major channel through which SWB is reduced.

This paper is structured as follows. Section 2 offers an overall review of the Wenchuan earthquake, the damage caused by the earthquake, and the reconstruction process. Our theoretical framework is also included in this section. Section 3 introduces the data and the empirical strategy. Section 4 presents the results. Section 5 reports the quantified income equivalence of well-being losses. Section 6 provides concluding observations.

2 Background and Theory

2.1 Wenchuan Earthquake

A catastrophic M8 earthquake hit Sichuan Province in China on May 12, 2008. It is named after its epicenter, Wenchuan county (Fig. 1). China's National Earthquake Relief Headquarter (2008) reported that 46 million residents were affected and approximately 1.5 million victims were housed in temporary settlements until September 2008. Wenchuan earthquake ultimately left 87,476 people either dead or missing, and 374,643 injured (International Disaster Database, 2008).

In addition to the numerous casualties, livelihoods were severely impacted, particularly in the rural areas. Many towns and villages, such as Beichuan county, were almost razed to the ground. An estimated 200 million square meters of rural housing was seriously damaged (State Council of China, 2008). The destruction of agricultural infrastructure impacted over one million farmers and destroyed their source of income. Thousands of mu[1] of farmland were destroyed, more than 50,000 greenhouses collapsed, and over 20,000 units of agricultural machinery were damaged (China's Ministry of Agriculture and Rural Affairs, 2008). According to Chen and Hu (2009), an additional 370,000 individuals were left unemployed and 51,000 families were left with no source of income. Non-agricultural residents temporarily lost their jobs. Farmers who had been deprived of their land

[1] Mu is a commonly used area unit for measuring agricultural land in China: 1000 mu is approximately 0.67 km^2.

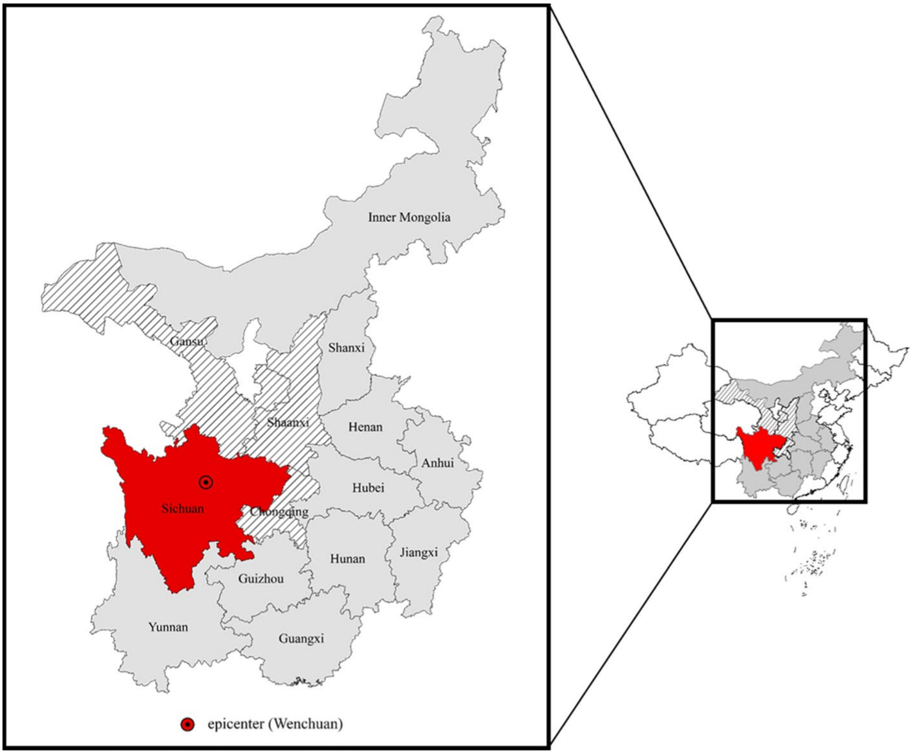


Fig. 1 Sichuan province and its neighboring provinces. *Source* Own representation. Wenchuan earthquake mostly impacted the Sichuan province, where the epicenter was located. The provinces indicated by the hatched pattern—Shaanxi, Gansu, and Chongqing—were partially affected by the earthquake. The 10 provinces in gray, located in central and western China, are at a similar level of development as Sichuan

accounted for the greatest proportion of the unemployed, and agricultural activity could only be resumed once production infrastructure had been restored.

An emergency aid program was launched immediately. The Chinese government promptly established an earthquake relief command center and initiated a first-level natural disaster response to link emergency systems at a national, provincial, city, and county level, which avoided potential deficiencies and inappropriate use of local resources due to unclear rescue tasks and fragmented management (Deng et al., 2010). Medical staff immediately began to rescue the injured, and 85% of the medical institutions in the affected areas started to accept victims within 30 min of the earthquake (Zhang et al., 2012). On day one, local health workers from Sichuan and around 16,000 health workers nationwide were deployed to 21 heavily affected counties, 446 towns, and 4185 village health units (Wu et al., 2008); this was accompanied by the joint rescue forces of the army and non-governmental organizations. Emergency rescue efforts continued for half a month: 94% of the total fatalities and 96% of the injured were found during the first two weeks (Zhang et al., 2012).

A grand plan for recovery and reconstruction followed. Governments at all levels had invested 67.2 billion yuan in earthquake relief funds by September 2008 (China's Ministry of Finance, 2008). The Overall Plan for Post-Wenchuan Earthquake Recovery and

Reconstruction was issued in September for 51 seriously affected counties[2] where a 1 trillion yuan fund was allocated for population relocation, housing provision, rural rebuilding, industry reconstruction, infrastructure renewal, and ecological restoration. The intensive recovery projects also stimulated economic performance. By 2017, the total local gross domestic product (GDP), local GDP per capita, and household income of the 39 most seriously hit areas in Sichuan had increased to approximately three times their pre-disaster levels (Sichuan Province's Bureau of Statistics, 2018).

2.2 Theoretical Framework

Understanding what elements prominently determine well-being is a premise for understanding the mechanisms through which earthquakes impact SWB. Cantril (1965) has shown that, despite different development levels and cultures, residents from 14 countries share similar considerations for happiness, including economic, health, family, work, and social aspects. Easterlin (2010, pp. 171–172) proposes a framework where life happiness is the net outcome of satisfaction in multiple life domains, reflecting both objective circumstances and subjective aspirations, and the four most influential domains are material conditions, family life, health, and work. In accordance with the two frameworks, five essential life domains—income, health, family, jobs, and social capital—are treated as the major determinants of well-being.

Life domains can be influenced simultaneously by the shock of an earthquake and the post-disaster recovery. Earthquakes have a significant impact on victims' income, work situations, health status, and family structure. Life satisfaction may be negatively affected by loss of property, deteriorating living conditions, injuries and trauma, and family dissolution (Kun et al., 2010). Victims may also experience social disconnection due to the loss of acquaintances or social tension due to the competition for scarce resources in the reconstruction stage (Li et al., 2015; Okuyama & Inaba, 2017; Wang et al., 2000). Post-disaster relief and restoration measures may to some extent offset the negative consequences of earthquakes, and this might be a reason why, for example, Rehdanz et al. (2015) find that the Fukushima disaster had not affected SWB through health, income, or employment. Nevertheless, recovery policies may not fully mitigate family dissolution caused by a disaster; moreover, post-earthquake social networks may be strengthened because survivors need to cooperate to get over difficulties (Zhao, 2013).

Equation (1) summarizes our theoretical framework. H represents a happiness function, W is an earthquake indicator, $\boldsymbol{D}$ is the objective outcome of various life domains, and $\boldsymbol{A}$ indicates a list of individual attributes. An earthquake, along with individual characteristics, reshapes objective outcomes of life domains and further influences well-being. Concurrently, individual characteristics appear in the happiness function to approximate subjective aspirations in order to capture that the association between well-being and objective outcomes of life domains could vary by individual characteristics.

$$H(W,\boldsymbol{A}) = H(\boldsymbol{D}(W,\boldsymbol{A}),\boldsymbol{A}) \tag{1}$$

[2] Based on the intensity of the earthquake and the extent of the damage, official assessments classified 237 counties into three types: severely affected areas (10), strongly affected areas (41), and moderately affected areas (186). A full list is available at http://www.gov.cn/zwgk/2008-07/22/content_1052835.htm.

The empirical analysis will first spotlight a reduced form equation of well-being on the Wenchuan earthquake and individual attributes, and then test, based on Eq. (1), through which life domains the earthquake influenced happiness.

3 Data and Methodology

3.1 Data Description

We use data from the China General Social Survey (CGSS), one of China's earliest nationally representative continuous surveys jointly launched by the Renmin University of China and Hong Kong University of Science and Technology. The CGSS has completed 10 waves (2003, 2005, 2006, 2008, 2010, 2011, 2012, 2013, 2015 and 2017) that cover at least 100 counties/districts nationwide and accumulate a rich pooled cross-sectional dataset. Data at individual, family, community, and society levels are comprehensively collected to reflect social trends.

Our sample comprises two pre-earthquake waves (2005 and 2006) and four post-earthquake years (2010, 2012, 2015, and 2017). Data from the years 2003, 2008, 2011, and 2013 are excluded because the 2003 wave covers only urban areas, the 2008 and 2011 waves have insufficient observations for Sichuan, and the 2013 wave disproportionally oversamples younger birth cohorts in Sichuan. Other than Sichuan, observations from 13 provinces in central and western China (Fig. 1) are used to construct the comparison group. Five provinces in the region (Xinjiang, Tibet, Qinghai, Ningxia, and Hainan) are removed because they are not included in all the waves of our sample. The exclusion of the five provinces should not affect our sample's representativeness as they account for a small proportion of China's total population. The CGSS only investigates adults (18 years old and above). We also exclude individuals who failed to report SWB and key characteristics, including gender, ethnicity, age, education, and location of residence. The full sample size for the main analysis is 32,205 adults with about 500–600 observations in Sichuan and approximately 4,300–5,000 observations in other provinces for each year.

SWB, the dependent variable, is derived from a self-reported happiness question in which respondents were asked "Overall, do you think your life is happy." Answers are based on five response options ranging from "very unhappy" to "very happy." We measure SWB on a 1 to 5 scale with a larger number representing greater happiness. Self-reported happiness has been proven as a valid measurement (Helliwell et al., 2012) and been widely used in studies, including studies in China (e.g., Morgan & Wang, 2019).

Life domains, the mechanism variables through which the earthquake may have affected well-being, are measured as follows. Income is measured by the equivalized household income which divides the household annual total income by the equivalent household size. The household total income is adjusted to the level in 2005 using annual province-based consumer price indices. The equivalent household size assigns 1 to the major respondent, 0.5 to other family members aged 14 and above, and 0.3 to members aged below 14, according to the modified OECD equivalence scale. The income variable is in the form of natural logarithm. Employment status is a dummy variable with 1 indicating employed and 0 unemployed and those not in the labor markets. Health is a self-evaluated perception of health rated from 1 (very unhealthy) to 5 (very healthy). Another category, "extremely healthy," appears in the 2005 wave and is merged with "very healthy." Family dissolution is measured by two indicators. The divorce dummy takes 1 for divorcees and 0 otherwise;

Table 1 Descriptive statistics of the main variables

Variables	Mean	S.D.	Min.	Max.	N
Dependent variable					
SWB (1–5)[a]	3.61	0.86	1	5	32,205
Mechanism variables					
Income (natural logarithm of equivalized household income, yuan)[b]	8.92	1.11	1.64	15.80	28,920
Health (1–5, "very unhealthy" to "very healthy")[c]	3.51	1.14	1	5	28,800
Divorce (1 = divorced)[d]	0.02	0.14	0	1	32,201
Widow (1 = widowed)[e]	0.08	0.27	0	1	32,201
Job (1 = employed)[f]	0.65	0.48	0	1	32,139
Social (1–5, "very rare" to "very close")[g]	2.51	1.11	1	5	27,147
Control variables					
Gender (1 = male)[h]	0.48	0.50	0	1	32,205
Age[i]	48.00	15.68	18	103	32,205
Han (1 = Han ethnicity)[j]	0.90	0.30	0	1	32,205
Middle (1 = middle school)[k]	0.29	0.46	0	1	32,205
High (1 = high school and above)[l]	0.25	0.43	0	1	32,205
Urban (1 = urban residents)[m]	0.47	0.50	0	1	32,205

[a]The dependent variable SWB is self-reported happiness ranging from 1–5. For mechanism variables, [b]Income is the natural logarithm of the equivalized household income adjusted to the level in the year 2005 based on provinces' annual consumer price index (CPI); [c]Health is a self-evaluated health status (1–5); [d]Divorce is 1 for divorcees and 0 otherwise; [e]Widow is 1 for widows and 0 otherwise; [f]Job is 1 for the employed and 0 for the unemployed and those not in the labor markets; [g]Social refers to the frequency of contact with friends and relatives (1–5). For major individual controls, [h]Gender is 1 for male; [i]Age confirms adult respondents in CGSS; [j]Han ethnicity; [k]Attainment of secondary-school education level; [l]Educational level of high-school or above; and [m]Living in an urban area. All data are from the CGSS

the widowhood indicator assigns 1 to widows and 0 to others. Bjørnskov (2006) points out that social networks, social trust, and social norms are essential facets of social capital. Due to limitations in data availability, we only measure social network based on a survey question that records "frequency of contact with your friends/relatives," where responses range from 1 (very rare) to 5 (very close). The social capital variable is available for all years except 2006.

Some key personal characteristics that may affect SWB are also considered (Dolan et al., 2008), including gender, age, ethnicity (Han or non-Han), education level (primary school and below, middle school, or high school and above), and location of residence (urban or rural). A few additional individual variables (*hukou* status,[3] party membership, and household size) and provincial features (population size, gender and age composition, and education structure, collected from China Statistical Yearbooks) are included for the robustness checks (see Table A1 in the online appendix for variable descriptions). Table 1 presents the mean, standard deviation, minimum, maximum, and total observations for the dependent variable, mechanism variables, and major control variables of our analysis.

[3] *Hukou* is a China-specific household registration and population management system. A person is registered as either an agricultural or non-agricultural resident.

3.2 Empirical Strategy

We adopt a DID approach to identify the causal effect of the Wenchuan earthquake on well-being. Differentiating post-earthquake and pre-earthquake happiness in Sichuan, the affected province (treatment group) yields a combination of the well-being effect of the earthquake and the natural evolvement of happiness. Using the same procedure for unaffected provinces (control group), only the natural change in SWB is obtained. If the natural shift in happiness in the treatment group is the same as that of the control group when there were no earthquakes—often called the parallel-trend assumption—any additional difference between the two temporal differences would reveal the causal effect of the Wenchuan earthquake on SWB. The DID method allows for unobserved determinants of happiness in different levels in the two groups, and rules out all unobservables that confound the causal effect as long as the parallel-trend assumption holds. The DID approach is implemented with a linear model as set out in Eq. (2), which represents a reduced form model of Eq. (1).

$$SWB_{ipt} = \beta Sichuan_p \times Post_t + \theta Sichuan_p + \rho Post_t + \boldsymbol{X}_{ipt}\gamma + u_{ipt} = \beta Quake_{pt} + \mu_p + \lambda_t + \boldsymbol{X}_{ipt}\gamma + \in_{ipt} \tag{2}$$

SWB_{ipt} is an individual i's happiness in the province p in the year t. $Sichuan_p$ is a binary variable for Sichuan province, and $Post_t$ is a binary variable indicating years after 2008. $\boldsymbol{X}_{ipt}$ is a set of control variables for personal characteristics, including gender, age and squared age, ethnicity, level of education, and the urban indicator for the baseline model and adding more individual and provincial characteristics for the robustness examination. The first half of Eq. (2) presents a basic form of DID with covariates, and the coefficient β, essentially the (conditional) double-difference of SWB, identifies the well-being effect of the earthquake. In the second half of Eq. (2), we define $Quake_{pt} = Sichuan_p \times Post_t$ as the indicator for the Wenchuan earthquake. We further extend the DID form to a more general model of two-way fixed effects (TWFE), where μ_p and λ_t are province fixed effects and year fixed effects intended to capture location-specific and time-specific characteristics, respectively. The TWFE model, usually regarded as a generalized DID setting, is preferred to the traditional DID form in our analysis because the former is able to capture unobservables more comprehensively.[4] u_{ipt} and ϵ_{ipt} are the error terms in the two forms. For convenience, we still call the TWFE setting as a DID approach.

Although the DID method allows the treatment and the control groups to have different underlying levels of SWB, the control group should be properly selected so that the two groups are similar enough to support the parallel-trend assumption. That is why we exclude provinces in northeastern, eastern, and southern China as they are far from Sichuan and their well-being trends may differ from the treatment group. Thus, the control group includes only 13 provinces (Fig. 1). For the main analysis, we regard partially affected provinces (Shaanxi, Gansu, and Chongqing, the provinces indicated by the hatched pattern in Fig. 1) as part of the control group. We examine the robustness of the estimates by

[4] In a two-group and two-period setting, TWFE is equivalent to DID. When the treatment is binary and the design is staggered, as in our case, the TWFE coefficient β is a weighted summation of multiple two-group two-period DID estimates (De Chaisemartin & d'Haultfoeuille, 2022). Recent studies have found that TWFE models may suffer from estimation biases caused by "forbidden comparison." However, in a scenario with binary treatment, staggered design, and unique treatment timing, TWFE is exempt from the problem (De Chaisemartin & d'Haultfoeuille, 2022). Our case satisfies all the conditions and therefore TWFE is a reasonable choice.

excluding the three provinces from the sample, or by treating them as a second treatment group.

Other than incorporating the partially affected provinces in the control group, there are at least two reasons our estimates would tend to be within the lower bounds of the true effects. First, changes in population composition and distribution due to the earthquake may lead to an underestimation of the well-being effect. Residents with a lower socio-economic status (SES) are more likely to live in poorly constructed houses in a fragile geological environment and are therefore more likely to perish in an earthquake. If so, post-earthquake observations in the treatment group tend to indicate higher SES and life satisfaction compared to the pre-earthquake population. Moreover, surviving victims may migrate to unaffected provinces and shrink the well-being gap between the treatment and control groups. During the post-disaster state-led relocation project, most of the 1.5 million victims who were resettled, moved to towns and cities adjacent to their own jurisdictions in Sichuan (State Council of China, 2008; Ge et al., 2010). Bound by the confidentiality rules of the CGSS, we are not able to identify the cities or counties where the interviewees reside; however, using the whole Sichuan province as the treatment group to a large extent avoids the issue created by population relocation.[5]

Second, spillover and crowding-out effects from Sichuan to other provinces may underestimate the well-being effect of the earthquake. On the one hand, the collapse of Sichuan's economic system may have negatively impacted the lives and well-being of residents in provinces with close economic ties to Sichuan. On the other hand, massive relief and recovery resources pouring into Sichuan may have crowded out financial support to other provinces and consequently impaired residents' well-being there.

To summarize, given the miscellaneous confounders, what the study actually derives is the lower bounds of the well-being effects of the Wenchuan earthquake. All the estimates deserve careful interpretation. Nevertheless, as long as we find negative effects, which is the case in our study, we can confirm the destructive nature of the earthquake.

Following standard procedures, we test the parallel-trend assumption with Eq. (3).

$$SWB_{ipt} = \sum_{\substack{t = 2005, 10, \\ 12, 15, 17}} \beta_t Wave_t \times Sichuan_p + \mu_p + \lambda_t + X_{ipt}\gamma + \in_{ipt} \tag{3}$$

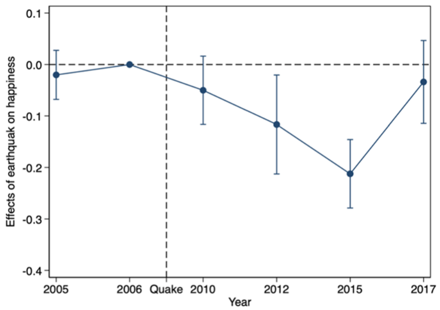
$Wave_t$ is a dummy variable representing whether individuals are in $Wave_t$. $Wave_{2006} \times Sichuan_p$ is dropped as a reference, and β_{2005} should be zero if the parallel-trend assumption holds. In practice, a statistically insignificant estimate for β_{2005} would endorse the assumption. Moreover, β_{2010} to β_{2017} estimate the well-being effects of the earthquake in each post-earthquake wave when the parallel-trend assumption is valid, so we are able to examine fully how the effects change in the short- and long-term.

[5] Although 141 out of the 181 counties in Sichuan were affected by the earthquake, there were also a number of unaffected residents in the western part of Sichuan that could not be ignored. Consequently, regarding the entire Sichuan as the treatment group may still have understated the earthquake's effect.

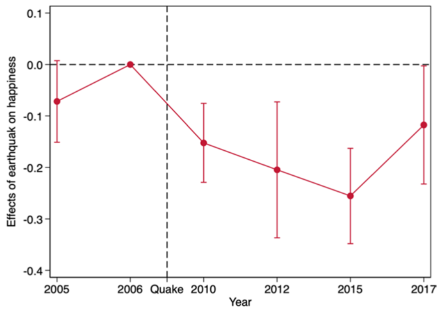
Table 2 Effects of the earthquake on well-being, OLS estimation

Dependent variable: Happiness (1–5)[a]	Full (1)	Full (2)	Rural (3)	Rural (4)	Urban (5)	Urban (6)
Quake[b]	−0.085*** (0.027)	−0.096*** (0.026)	−0.156*** (0.033)	−0.153*** (0.035)	−0.014 (0.028)	−0.023 (0.027)
Male		−0.034*** (0.009)		−0.040** (0.017)		−0.030** (0.013)
Age		−0.015*** (0.003)		−0.009*** (0.003)		−0.021*** (0.003)
Squared age/1000		0.180*** (0.031)		0.122*** (0.034)		0.244*** (0.034)
Han ethnicity		−0.110*** (0.031)		−0.126** (0.044)		−0.045 (0.030)
Middle school		0.163*** (0.015)		0.175*** (0.019)		0.147*** (0.028)
High school and above		0.310*** (0.019)		0.314*** (0.034)		0.300*** (0.031)
Urban		0.004 (0.017)				
Year FE	Y	Y	Y	Y	Y	Y
Province FE	Y	Y	Y	Y	Y	Y
Adjusted R^2	0.060	0.081	0.069	0.085	0.052	0.077
N1	3677	3677	1986	1986	1691	1691
N	32,205	32,205	17,047	17,047	15,158	15,158

[a]The dependent variable is self-reported happiness (1–5); [b]Quake is 1 for Sichuan after 2008 and 0 otherwise. Major individual controls are included in columns (2), (4) and (6), and year and province fixed effects (FEs) are included in all the columns. N and N1 represent the sample size and number of observations from Sichuan province, respectively. OLS estimation is applied and standard errors, clustered at a province level, are shown in parentheses. *** significance at the 1% level, ** significance at the 5% level



(a) Full sample



(b) Rural subsample

Fig. 2 Parallel-trend tests for happiness. Both figures plot estimates for β_t from Eq. (3) with 95% confidence intervals, with the covariates being identical to columns (2) and (4) of Table 2, respectively

4 Results

4.1 Main Results

Based on Eq. (2), Table 2 shows the ordinary least squares (OLS) estimates of the well-being effects of the Wenchuan earthquake for the full sample and all the rural and urban subsamples. Column (1) displays a negative and statistically significant correlation between well-being and the earthquake after controlling for the year and province fixed effects (FEs).

Individual control variables, including male respondents, age and its square, Han ethnicity, middle and high school indicators (primary school and below is the base category), and an urban dummy are added to column (2). The earthquake is associated with a 0.096 reduction in SWB on a scale of 1–5. By turning off the "Quake" indicator in column (2), we can predict that, without the earthquake, the average level of happiness in Sichuan province after 2008 would have been 3.594, increasing by 0.035 from the predicted level before 2008 (3.559), while the earthquake diminished happiness by 0.096, nearly three times the counterfactual increment of well-being. We will further quantify the loss in well-being at an income level in the next section. Our findings on the coefficients of the covariates are consistent with the literature: male respondents and the ethnic majority seem less happy; higher levels of education contribute to greater happiness; and the SWB–age relationship shows a typical U-shaped pattern.

The results summarized in the last four columns imply that rural residents suffered far more from the earthquake than urban populations in terms of well-being, and the overall decrease in SWB after the earthquake is primarily driven by the rural subsample. This is probably because the most stricken areas were in rural counties and because of the greater vulnerability of those living in a rural environment due to fragile housing and underdeveloped infrastructure. For the rest of the study, we will focus on the analysis of the full sample and the rural subsample, and use columns (2) and (4) as our baseline models.

A crucial assumption for DID is the parallel-trend assumption of well-being for the treatment and the control groups before the earthquake's shock. Taking 2006 as the reference year, Fig. 2 shows the estimates for β_t, based on Eq. (3), in the other years with 95% confidence intervals, for both the full sample and the rural subsample. The regression coefficients are shown in Table A2 of the online appendix.

Both subfigures present statistically insignificant coefficients for the year 2005, implying that the parallel-trend assumption has not been violated at the 5% level.[6] Coefficients for 2010, 2012, 2015, and 2017 represent the short- and long-term effects of the earthquake on well-being. Immediate post-disaster measures were sufficiently effective to offset the well-being impact of the earthquake so that a relatively smaller net effect could be observed in 2010. Temporary post-disaster aid gradually faded away while some of the consequences of the earthquake either remained or became even worse (e.g., badly injured family members passed away after several years.); consequently, the net effects in 2012 and 2015 were stronger. Eventually SWB started to recover in 2017. Once again, the well-being net effects for rural residents are more salient across all the years, either because of the greater impact of the earthquake or due to comparatively inadequate post-earthquake recovery measures.

4.2 Robustness Analysis

Table 3 shows the robustness of our baseline results. The first set of the robustness analysis, shown in Panel A, focuses on Sichuan's adjacent provinces (Shaanxi, Gansu, and Chongqing), which were only partially affected by the earthquake. In the baseline models of Table 2, Sichuan is the treatment group and the three provinces along with the others belong to the control group. In columns (1) and (3), we exclude the three adjacent provinces from the analysis and the estimates remain similar. In columns (2) and (4), Sichuan is the first treatment group, the adjacent provinces form a second treatment group, and the rest serve as the control group, so that we can separate the treatment effect of the earthquake in Sichuan from that in the adjacent provinces.

The two coefficients in column (2) and (4) of Panel A are estimates of β_1 and β_2 in Eq. (4), where $Adjacent_p$ is a binary indicator for the three adjacent provinces. The well-being effects of the earthquake in Sichuan are similar to the baseline estimates, while the net impact of the earthquake in Sichuan's adjacent provinces is statistically insignificant.

$$SWB_{ipt} = \beta_1 Post_t \times Sichuan_p + \beta_2 Post_t \times Adjacent_p + \mu_p + \lambda_t + \boldsymbol{X}_{ipt}\gamma + \in_{ipt} \tag{4}$$

Panel B of Table 3 examines how the results vary according to the model's specifications. Columns (1) and (3) incorporate additional individual and provincial covariates, including *hukou* status, membership of the Communist Party, household size, provincial population size, provincial cohort of high school students, provincial sex ratio, and population dependency ratio. The additional covariates are not controlled for in the baseline models because they are not sufficiently exogenous, but adding these covariates could help to eliminate more confounding effects. The coefficients in columns (1) and (3) are slightly weaker but remain robust.

Due to the ordinal nature of SWB, we estimate an ordered probit model and calculate the average partial effects of the earthquake on the probability of happiness being at specific levels, following Puhani's (2012) framework of DID in non-linear models. Columns (2) and (4) show that the earthquake decreases the probability of being happy (4) and very

[6] The p value for the 2005 coefficient in the rural subsample is 0.072, indicating that the parallel-trend assumption is marginally violated. At the 10% level, the upward pre-trend indicates that the rural SWB in Sichuan province would have grown faster than that of other provinces had the earthquake not happened. As a result, the dynamic effects of the earthquake on happiness in Fig. 2b are likely the lower bounds of the true shocks, implying that the earthquake may have impacted the rural SWB more heavily than what the subfigure has revealed.

Table 3 Robustness analysis

Panel A. Alternative treatment and control groups

Dependent variable: Happiness (1–5)	Adjacent provinces excluded Full (1)	Adjacent provinces as another treatment Full (2)	Adjacent provinces excluded Rural (3)	Adjacent provinces as another treatment Rural (4)
Quake (Sichuan)	−0.093*** (0.023)	−0.094*** (0.023)	−0.146*** (0.035)	−0.146*** (0.035)
Quake (adjacent provinces)		0.012 (0.107)		0.049 (0.122)
Baseline covariates	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Province FE	Y	Y	Y	Y
Adjusted R^2	0.086	0.081	0.092	0.085
N1	3677	3677	1986	1986
N2		4835		2748
N	27,370	32,205	14,299	17,047

Panel B. Alternative model specifications

Dependent variable: Happiness (1–5)	Additional covariates Full (1)	Ordered probit Full (2)	Additional covariates Rural (3)	Ordered probit Rural (4)
Quake	−0.079** (0.027)		−0.113** (0.042)	
Average partial effects of the quake on the probability of happiness being equal to				
1		0.003*** (0.000)		0.005*** (0.001)
2		0.012*** (0.003)		0.020*** (0.004)
3		0.027*** (0.006)		0.044*** (0.010)
4		−0.015*** (0.003)		-0.031*** (0.005)
5		−0.026*** (0.006)		-0.039*** (0.009)
Baseline covariates	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Province FE	Y	Y	Y	Y
Adjusted R^2	0.093	0.081	0.097	0.136

Table 3 (continued)

Panel B. Alternative model specifications

Dependent variable: Happiness (1–5)	Additional covariates Full (1)	Ordered probit Full (2)	Additional covariates Rural (3)	Ordered probit Rural (4)
N1	3672	3677	1984	1984
N	32,127	32,205	17,006	17,047

The dependent variable is self-reported happiness (1–5). In Panel A, columns (1) and (3) exclude Shaanxi, Gansu, and Chongqing; columns (2) and (4) treat the three provinces as a second treatment group. In Panel B, columns (1) and (3) add covariates, including a *hukou* dummy, a membership of the Communist Party dummy, household size, provincial population size, provincial cohort of high school students, provincial sex ratio, and old dependency ratio; columns (2) and (4) estimate ordered probit models and present average partial effects of the earthquake on the probability of happiness at specific levels. All the columns include baseline covariates, year fixed effects (FEs), and province FEs as in columns (2) and (4) of Table 2. N, N1, and N2 represent sample size, the number of Sichuan observations, and the number of observations from Shaanxi, Gansu, and Chongqing, respectively. Pseudo-R-squared is reported for ordered probit models. Standard errors, clustered at the province level, are shown in parentheses. *** significance at the 1% level, ** significance at the 5% level happy (5), and the estimates are in line with earlier studies (Carroll et al., 2009; Luechinger & Raschky, 2009; Rehdanz et al., 2015). Our results therefore remain robust after a series of examinations.

4.3 Mechanism Analysis

Given the detrimental effects of the Wenchuan earthquake on the well-being of victims in Sichuan, we further explore through which channels the earthquake exerted these adverse shocks. Based on our theoretical framework, we probe five mechanisms: income, health, family, jobs, and social capital. By replacing the dependent variable of the baseline models with each mechanism variable, we estimate the function $\boldsymbol{D}(W, \boldsymbol{A})$ in Eq. (1) and determine to what extent the earthquake affected various life domains. Panels A and B of Table 4 summarize the mechanisms analyses for the full sample and the rural subsample, respectively. The dependent variables are measures of life domains whose definition and descriptive statistics are described in the data description section. When divorce and widowhood are mechanism variables, we restrict the zero-valued respondents of the two dummies to the currently married or those cohabitating with unmarried partners, to highlight life transitions from being married to divorce or widowhood in the wake of the earthquake. The rest of the regressions are based on all individuals with available information on the mechanism variables. The independent variables are identical to those in the baseline models of Table 2. Table 4 is based on the linear models. The results remain robust if probit models are estimated for divorce, widowhood, and employment status, and ordered probit models are used for health and social capital.

The parallel-trend assumption also needs to hold for the mechanisms analyses so that we are able to interpret all the coefficients in Table 4 as the causal effects of the earthquake on the mechanism variables. In Panel A, columns (1), (2), and (5) satisfy the parallel-trend assumption with the baseline model setting of Table 2. Pre-earthquake trends of divorce and widowhood are not parallel in the baseline setting. We manage to satisfy the assumption by matching each Sichuan individual in a year with similar non-Sichuan residents of the same year before implementing the DID regressions, usually called a DID matching strategy (Smith & Todd, 2005), and report the results in columns (3) and (4).[7] In Panel B, columns (1) to (3) and column (5) satisfy the parallel-trend assumption with the baseline setting, and the mechanism variable "Widow" is excluded as the assumption is violated even with the DID matching strategy. Social capital is unavailable in 2006 so the parallel-trend assumption cannot be tested. We apply the DID matching strategy to columns (6) of Panel A and Panel B to make the coefficients as causal as possible.

4.3.1 Income and Employment

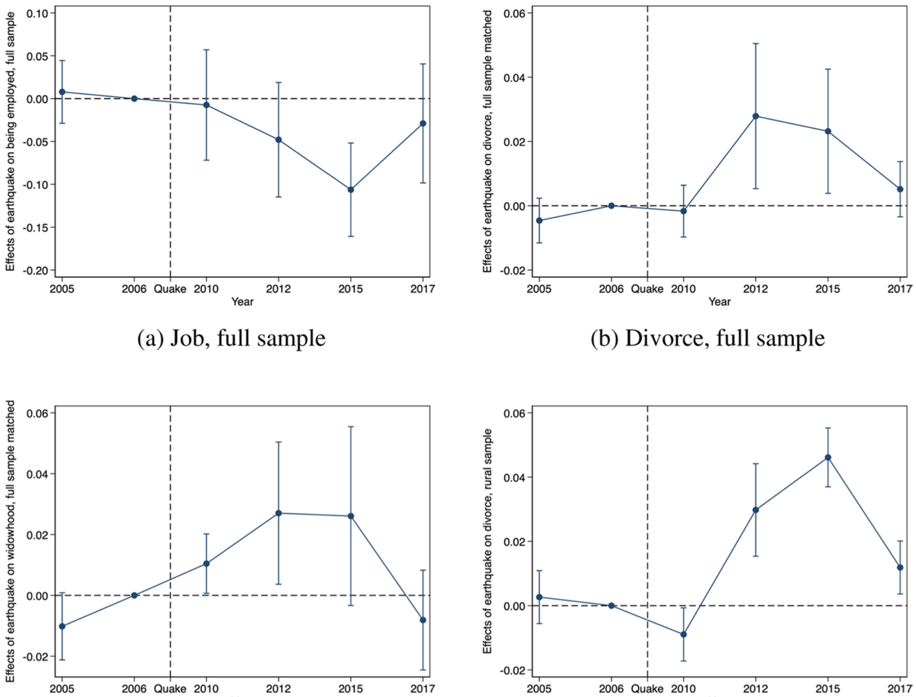
The statistically insignificant coefficients in columns (1) of Panels A and B imply that, despite the earthquake's substantial negative shocks to income, post-disaster recovery

[7] We calculate the propensity scores of being treated (being in Sichuan province) for each individual in each year, using a logit model on gender, age, squared age, ethnicity, education, and place of residence. Then we match each Sichuan individual in a year with non-Sichuan residents of the same year having similar propensity scores using the method of kernel matching. We further confirm that the parallel-trend assumption still holds for happiness with the DID matching strategy, and the post-earthquake dynamics of happiness are similar to those presented in Fig. 2.

Table 4 Mechanisms analysis

Dependent variable:	Income[a] (1)	Health[b] (2)	Divorce[c] (3)	Widow[d] (4)	Job[e] (5)	Social[f] (6)
Panel A. Full sample						
Quake	0.077 (0.048)	0.090 (0.066)	0.015*** (0.005)	0.020*** (0.006)	−0.052** (0.019)	0.179** (0.064)
Baseline covariates	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Province FE	Y	Y	Y	Y	Y	Y
Adjusted R^2	0.348	0.208	0.022	0.253	0.226	0.328
N1	3454	3224	3011	3294	3672	3023
N	28,920	28,800	23,915	26,037	32,139	24,415
Panel B. Rural subsample						
Quake	0.017 (0.069)	0.112 (0.095)	0.017*** (0.003)		−0.034 (0.026)	0.203*** (0.066)
Baseline covariates	Y	Y	Y		Y	Y
Year FE	Y	Y	Y		Y	Y
Province FE	Y	Y	Y		Y	Y
Adjusted R^2	0.253	0.198	0.012		0.243	0.395
N1	1880	1693	1653		1982	1599
N	15,414	15,167	14,513		17,001	11,546

Measures of the five life domains serve as dependent variables in columns (1)–(6): [a]Income is the natural logarithm of the equivalized household income adjusted to the level in the year 2005 based on provinces' annual consumer price index (CPI); [b]Health is self-evaluated health status (1–5); [c]Divorce is 1 for divorcees and 0 for those currently married or cohabitating with a partner; [d]Widow is 1 for widows and 0 for those currently married or cohabitating with a partner; [e]Job is 1 for the employed and 0 for the unemployed and those not in the labor markets; and [f]Social refers to frequency of contact with friends and relatives (1–5). Independent variables are identical to the baseline models of Table 2. N and N1 represent the sample size and number of observations from Sichuan province, respectively. Standard errors, clustered at the province level, are shown in parentheses. *** significance at the 1% level, ** significance at the 5% level. FE: Fixed effect



(a) Job, full sample

(b) Divorce, full sample

(c) Widow, full sample

(d) Divorce, rural subsample

Fig. 3 Parallel-trend tests for mechanism variables. All figures plot estimates of the year-by-year effects of earthquake on mechanism variables, relative to the base year of 2006, with 95% confidence intervals, and covariates being identical to columns (2) and (4) of Table 2, respectively

policies may have been effective in offsetting these influences. For example, the 18 counties most damaged were paired with 18 of the richest provinces, where the latter were obliged to transfer at least 1% of their previous year's revenue to the matched counties for three consecutive years (2008–2010; Bulte et al., 2018).

Moreover, the Sichuan government swiftly created over 800,000 jobs to mitigate the shock to employment. Figure 3a presents the parallel-trend test and post-earthquake dynamics of employment based on column (5) of Panel A in Table 4. The statistically insignificant effects in 2010 and 2012 imply the post-disaster policy has essentially undone the short-term impact on jobs, but many informal and temporary jobs may have disappeared in the long run so that the victims suffer from negative shocks on employment in 2015 before they could fully recover with formal jobs in 2017. Column (5) of Panel B implies post-earthquake aid may be stronger in rural areas so that the net effect on rural employment is statistically insignificant. The living allowances and housing subsidies (including loans) granted directly to rural victims, roughly estimated, exceeded 100 billion yuan (Lu et al., 2014). The whole investment package was designed to have a positive impact on employment and income, and limit the depressive effect of the destruction caused by the earthquake (Dunford & Li, 2011).

Another factor that played a role in rural areas is strategic behavior adjustment. In a study of droughts in Australia, Carroll et al. (2009) argue that when the situation were to worsen, there would be out-migration from affected regions, and within the affected regions both the composition of industries and alternative (agricultural) production methods would change. This phenomenon was also observed after the Wenchuan earthquake. Lu et al. (2014) find that due to the loss of agricultural income after the earthquake, farmers migrated to earn income from non-agricultural jobs, which could, to a large extent, offset the income and employment shocks from the earthquake.

The significant employment effect of the earthquake in the full sample could explain why happiness declines, while the insignificant coefficient for the rural subsample is inconsistent with the fact that rural victims have suffered greater well-being losses from the earthquake. Accordingly, we take a cautious attitude towards this result and employment status will not be regarded as a crucial mechanism in the study.

4.3.2 Health

The insignificant effects of the earthquake on health in columns (2) of Panels A and B need to be interpreted with caution. It is possible that emergency medical rescue efforts and post-earthquake treatments (Wu et al., 2008) counteracted the earthquake's harmful impact on health, but their impact may be understated for a number of reasons. First, it is inevitable in a huge earthquake that some residents may be omitted from a survey because, for instance, they were badly injured, died, or moved to other provinces because of the trauma (Yamamura, 2012). Chen et al. (2009) investigate 1,243 victims in five of the worst hit counties, where the disabled and incapacitated accounted for about 10% of the victims. Second, the health question of the CGSS was changed in the 2010 wave to "How do you experience your body's health" instead of asking respondents to "Evaluate your health status," which may have induced people to focus only on physical rather than mental conditions.

4.3.3 Divorce and Widowhood

Columns (3) and (4) of Panel A and column (3) of Panel B show that the earthquake significantly increased the probability of divorce and of being widowed. Becker et al. (1977) indicate that unanticipated events may destabilize marriage. This study, among others (e.g., Martin & Bumpass, 1989; White, 1990), also reveals that the likelihood of divorce is negatively associated with SES. It is possible that the earthquake reduced family members' SES and contributed to higher divorce rates before their SES could be substantially restored. In addition, the earthquake killed people and resulted in widowed families, and badly injured family members were more likely to pass away a few years later, which would have exacerbated the problem of widowhood. Figures 3b–d present the parallel-trend tests and post-earthquake dynamics of divorce and widowhood based on columns (3) and (4) of Panel A and column (3) of Panel B in Table 4. The effects of the earthquake on divorce and widowhood are most salient in 2012 and 2015, implying that the issues of divorce and widowhood may have emerged gradually after the earthquake, and are consistent with the happiness dip in Fig. 2.

The significantly higher rates of divorce and widowhood caused by the earthquake explain why a loss in well-being could still be detected despite compensation for loss of post-earthquake income and employment. As Easterlin (2010) points out, the formation and dissolution of unions are essential to determine satisfaction with family life. Losing a job or other sources of income could be temporary and repaired by outside forces or personal adjustment, while being separated from life partners may cause long-term trauma that public policies can hardly address. Lucas et al. (2003) report that adaptation to widowhood may take eight years on average; this is consistent with what Figs. 2 and 3c show in the 2017 wave.

4.3.4 Social Capital

Post-earthquake recovery of social capital could even surpass the damages. The positive and significant estimates in columns (6) of Panel A and Panel B indicate that the victims in Sichuan had stronger social ties with friends and relatives than they did before the Wenchuan earthquake. As a result, social capital is unlikely to be a channel through which the earthquake deteriorates happiness.

Not only that, the effect of social capital on SWB remains ambiguous. Yamamura et al. (2015) find that the positive relation between social trust and happiness was strengthened after the Great East Japan Earthquake, which mitigated the disaster shock. Social capital contributes to post-disaster recovery with some evidence from the Wenchuan earthquake as well (Zhao, 2013). However, a few empirical studies (Chen & Meng, 2010; Xin et al., 2009) fail to find significant benefits from social networks, probably because social networks are informal and fragile, especially in the case of victims in rural areas. Our sample presents positive correlations between social capital and happiness (Table A3).

Classic mediation analysis further compares the coefficient of the earthquake with controlled mediators to the coefficient without mediators, but the estimators are usually inconsistent due to the mediators' endogeneity. We follow the standard procedure of mechanism analysis in the literature examining the causal effect of an event, and verify the linkages between the earthquake and multiple mechanisms empirically (Table 4) while building the bridges between the mechanisms and SWB theoretically (Sect. 2.2). We supplement the evidence in Table A3 by showing how the mechanisms relate to SWB in our sample. The results confirm that all the mechanisms are significantly connected to SWB at the 1% level except that being employed in the rural subsample is significantly correlated with happiness at the 10% level. To summarize, evidence supports that divorce and widowhood may be crucial mechanisms through which the earthquake has affected happiness.

4.4 Heterogeneity Analysis

The well-being of populations with different characteristics may be affected differently by the earthquake. We use Eq. (5) to examine how the effects of the Wenchuan earthquake on SWB vary by specific individual characteristics Z_{ipt}, which include age, education, and having a basic pension or medical insurance. δ measures the heterogeneous effects of the earthquake on well-being. $\boldsymbol{X}_{ipt}$ contains the baseline covariates as well as Z_{ipt}. For the model's completeness, we also include the interactions between each pair of the variables among $Sichuan_p$, $Post_t$, and Z_{ipt}.

$$SWB_{ipt} = \delta Quake_{pt} \times Z_{ipt} + \beta Quake_{pt} + \theta Sichuan_p \times Z_{ipt} + \rho Post_t \times Z_{ipt} + \mu_p + \lambda_t + \boldsymbol{X}_{ipt}\gamma + \in_{ipt} \tag{5}$$

Table 5 summarizes the estimates of δ, for both the full sample and the rural subsample. Columns (1) and (2) show that older adults and less educated respondents are more vulnerable to the shock of the earthquake (statistically insignificant for the rural subsample), which is consistent to findings that populations with disadvantaged SES were more vulnerable in terms of SWB during China's economic transitions in the late 1990s and early 2000s (Easterlin et al.,

Table 5 Heterogeneity analysis

Dependent variable: Happiness (1–5)	(1)	(2)	(3)	(4)
Panel A. Full sample				
Age*quake	−0.003** (0.001)			
Middle school*quake		0.056 (0.036)		
High school*quake		0.112** (0.044)		
Pension*quake			0.062 (0.037)	
Medical insurance*quake				0.294*** (0.041)
Baseline covariates	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Province FE	Y	Y	Y	Y
Adjusted R^2	0.082	0.082	0.059	0.061
N1	3677	3677	2920	2965
N	32,205	32,205	27,152	27,525
Panel B. Rural subsample				
Age*Quake	−0.001 (0.002)			
Middle school*quake		0.054 (0.055)		
High school*quake		0.006 (0.068)		
Pension*quake			0.314*** (0.099)	
Medical insurance*quake				0.624*** (0.065)
Baseline covariates	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Province FE	Y	Y	Y	Y
Adjusted R^2	0.085	0.085	0.048	0.050
N1	1986	1986	1321	1350
N	17,047	17,047	12,891	13,102

The dependent variable is self-reported happiness (1–5). The quake indicator is interacted with age, education dummies, a pension dummy, and a medical insurance dummy in columns (1) to (4), respectively. Columns (3) and (4) further control for the pension and medical insurance dummies. All the columns include interactions between each pair of the variables among Sichuan dummy, a post-earthquake dummy, and the characteristics used for the heterogeneity analysis. N and N1 represent sample size and the number of observations from Sichuan province, respectively. Standard errors, clustered at a province level, are shown in parentheses. *** significance at the 1% level, ** significance at the 5% level. FE: Fixed effect

Table 6 Quantifying the well-being loss with income

Dependent variable: Happiness (1–5)[a]	Full (1)	Rural (2)
Quake	−0.105*** (0.028)	−0.140*** (0.037)
Income (natural logarithm of equivalized household income, yuan)[b]	0.156*** (0.008)	0.149*** (0.011)
Baseline covariates[c]	Y	Y
Year FE	Y	Y
Province FE	Y	Y
Adjusted R^2	0.110	0.113
N1	3,454	1,880
N	28,920	15,414

[a]Happiness, the dependent variable, is self-reported happiness (1–5); [b]Income is the natural logarithm of the equivalized household income adjusted to the level in the year 2005 based on provinces' annual consumer price index (CPI); and [c]Other covariates are identical to the baseline models of Table 2. N and N1 represent sample size and the number of observations from Sichuan province, respectively. Standard errors, clustered at a province level, are shown in parentheses. *** significance at the 1% level. FE: Fixed effect

2012, 2017; Morgan & Wang, 2019). In a study on floods, Luechinger and Raschky (2009) find that compulsory insurance could significantly mitigate the negative impact on SWB. As columns (3) and (4) illustrate, participation in basic pension or medical insurance programs could mitigate the well-being damages caused by the earthquake, except that the estimate in column (3) of Panel A is only statistically significant at the margin (p value = 0.117).

5 Quantifying Loss in Well-Being

When evaluating the total cost of a natural disaster, people tend to gauge it based on the physical damage and neglect the loss in well-being. A natural disaster could be viewed as "public bads" for which there is no tradable market or price, which challenges traditional valuation methods (e.g., hedonic or contingent valuation methods). However, we have the option of employing a life satisfaction analysis (LSA) to assess the intangible costs with our happiness data. Luechinger and Raschky (2009) compare several valuation methods and highlight the advantages of LSA.

Under the hypothesis of rational economic agents, maximal utility is maintained when $\left|MU_{inc}\Delta Inc\right| = \left|MU_{quake}\Delta Quake\right|$, other determinants of utility being constant. MU_{inc} and MU_{quake} are the marginal utilities of income and earthquake, respectively. Empirically, utility could be proxied by SWB, as Kahneman et al. (1997) indicate that life satisfaction could be regarded as a well-defined form of experienced utility. The two marginal utilities can thus be obtained by regressing SWB on income and earthquake, conditional on other covariates. We can further acquire the willingness to pay (WTP) or the marginal rate of substitution between income and earthquake (Eq. (6)) to suggest how much income a person would be willing to sacrifice to avoid an earthquake, or, in another words, how much income would compensate a person for experiencing a disaster in terms of SWB.

$$WTP \ \ (MRS) = \left|\frac{\Delta Inc}{\Delta Quake}\right| = \left|\frac{MU_{quake}}{MU_{inc}}\right| \tag{6}$$

Table 6 estimates marginal utilities with respect to the earthquake and equivalized household income for the full sample and the rural subsample. The income variable is included in the form of natural logarithm to alleviate the influence of outliers and capture the nonlinear relations between SWB and income. Coefficients in column (1) imply that $MU_{inc} = 0.156/Income$. The post-earthquake average equivalized household income (adjusted to the year 2005) of Sichuan residents is 17,259 yuan, and then the overall WTP is approximately 11,617 yuan (0.105*17,259/0.156), which amounts to 67% of the average equivalized household income. The post-earthquake average equivalized household income (adjusted to the year 2005) of Sichuan rural residents is 10,197 yuan, and similarly, the rural WTP is about 9,581 yuan (0.140*10,197/0.149), which is about 94% of the rural average equivalized household income.

The WTPs computed for the Wenchuan earthquake are much larger than those for other disasters in the literature. Carroll et al. (2009) state that spring droughts in rural Australia cause an average loss of 38% in annual household income. In a study on floods in Europe, Luechinger and Raschky (2009) conclude that people are willing to spend 24% of their average annual household income to avoid a particular flood. For the Fukushima earthquake, a similar case to the one covered by our study, Rehdanz et al. (2015) find that a person living within a 150–300 km range of the epicenter experiences a reduction in happiness worth 70% of their household's average annual income, while for a person living within 150 km of the event, it is up to 240%, similar to our estimates.

6 Conclusions

By utilizing six waves of CGSS data and the DID method, this study is among the first to identify the causal well-being effect of China's 2008 Wenchuan earthquake. We explored its long-term influence as well as potential mechanisms to quantify the equivalent monetary loss. We detected a significant reduction in SWB among Sichuan residents compared to their neighboring counterparts. This depressive effect was sustained for nearly 10 years, despite the finding that SWB tends to return to the pre-earthquake level in the long-term. We gauged the integrated net outcome of the earthquake per se along with the relief and recovery programs after the disaster, and found that the effect remains robust after a series of checks. As for impact channels, losses concerning the economic aspects (income and jobs) as well as the health of residents appeared to be largely compensated owing to enormous investment in post-earthquake reconstruction. Social capital was strengthened after the earthquake so that SWB benefited from interpersonal connections.

The significantly higher rates for divorce and widowhood could explain why Sichuan residents continued to suffer a deterioration in life satisfaction, particularly once the relief programs were phased out in the medium term. Catastrophic natural disasters, such as huge earthquakes, impact victims' well-being through more hidden channels, including, but not limited to, family structure (e.g., family dissolution and less parenting of children because adults have to work outside). While a typical reconstruction program mainly focuses on economic recovery, these "forgotten" corners often fail to attract the attention of policymakers. Yet this aspect of well-being loss should not be disregarded, for the results of our analysis estimate its monetary equivalence to be 67% of the average equivalized household income. Due to the limitation of our datasets, crucial life domains through which the earthquake could affect happiness may not be measured accurately and comprehensively. Further research is needed to examine more potential mechanisms.

Prominent inequality was found in the well-being impact of the earthquake. Rural populations were more severely hit, such that the income equivalent loss in SWB was as high as 94% of the rural equivalized household income. Older adults, the less educated, and those without social insurance are more vulnerable to earthquake shocks. Post-disaster policies should focus on disadvantaged groups to help them recover as much as possible.

In the context of the coronavirus disease 2019 (COVID-19) pandemic, our study concerning the well-being effect of natural disasters sheds some light on the design of practical programs for disaster prevention and recovery. The content of relief efforts and their cost–benefit analyses should not simply concentrate on economic aspects. It is also necessary to deliberate further on what public policies can do for affected populations—often permanently scarred—particularly when intensive financial aid is phased out. Variations in human welfare due to natural disasters always call for deeper academic research. At a grassroots level, long-term assistance with more comprehensive humanitarian features during the post-disaster stage should be elaborated, especially for those from a disadvantaged socioeconomic background.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10902-022-00609-z.

Funding This work was supported by the "Thematic Research Project on China's Income Distribution" (No. 21XNLG03) with funding from the research fund of Renmin University of China.

Declarations

Conflicts of interest The authors declare that they have no conflict of interest.

Ethical Approval This research was conducted in accordance with the ethical guidelines of the local university and with the Ethical Standards of the 1964 Declaration of Helsinki.

Informed Consent Informed consent was obtained from all participants.

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