

Disaster, displacement, and distress: Earthquake intensity and persistent mental health effects in urban New Zealand

Thoa Hoang

Thoa.hoang@vuw.ac.nz

Victoria University of Wellington

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Abstract

This study estimates the causal effect of spatially varying earthquake intensity on long-term mental health outcomes using linked administrative panel data on 236,856 adults in Greater Christchurch (2007–2019). Exploiting meshblock-level Modified Mercalli Intensity (MMI) variation as a continuous treatment in a difference-in-differences design with individual fixed effects, we find that each unit increase in MMI raises psychiatric medication use by 5.3% (0.051 medications per person-year), with effects persisting six to eight years post-disaster. Impacts are heterogeneous: point estimates are larger for adults aged 65 and older, those without tertiary education, and individuals with severe housing damage, with these differences confirmed by formal tests; effects are also directionally larger for women, though the gender gap itself is not statistically significant. Mediation analysis shows that employment disruption explains the effect among working-age adults but not among the elderly - the most affected group - pointing to unobserved channels such as social network disruption. Hospital admissions rise modestly (5.5%), confirming that exposure primarily generates mild-to-moderate distress. These findings call for differentiated recovery policies targeting labor market support for working-age adults and community-based interventions for older populations.

1. Introduction

Urban economies are acutely exposed to natural disaster risk, and the costs of major seismic events extend well beyond physical infrastructure damage. Earthquakes disrupt labor markets, displace residents, and sever the social and economic networks that sustain urban well-being. While the immediate economic consequences – job loss, property destruction, displacement – are relatively well documented, the long-run effects on population health operating through these channels remain poorly understood. This paper exploits spatially detailed variation in earthquake intensity across an urban area to identify the causal effect of seismic exposure on mental health, and to decompose that effect into its underlying socioeconomic pathways.

On February 22, 2011, a magnitude 6.2 earthquake struck Christchurch, New Zealand, killing 185 people, injuring over 8,000, and causing widespread destruction across the city. Eight years later, mental health medication use remained elevated by 5.3% in the most affected neighborhoods, with vulnerable populations experiencing substantially larger and more persistent impacts. This illustrates a broader pattern in urban disaster recovery: mental health consequences extend far beyond the immediate crisis period, operating through labor market disruption, residential displacement, and housing damage in ways that primary health-system responses rarely address.

A substantial literature links earthquake exposure to psychological distress, from acute stress reactions to chronic PTSD, depression, and anxiety (Paudel & Ryu, 2018; Norris, 2006; Galea, Nandi, & Vlahov, 2005; Raker et al., 2019), conditions that are often persistent and inadequately managed post-disaster (Davidson et al., 1991; Kessler, 2000; Jia et al., 2010; Akram et al., 2024). Critical gaps remain, however: most studies focus on short-term effects, rely on survey-based methods lacking population coverage, or do not rigorously identify causal mechanisms or pre-existing trend differences (Harada et al., 2015; Paudel, Sah, & Khanal, 2025). Few exploit spatially granular exposure measures, leaving the dose-response relationship between seismic severity and mental health poorly identified.

Recent research has begun to address the socioeconomic channels through which disasters affect mental health, linking employment disruption and housing damage to post-earthquake psychological trajectories (Bai & Li, 2021; De & Thamarapani, 2022; Kirchberger, 2017; Shidiqui et al., 2022). Yet evidence on long-term causal pathways remains scarce, and no study has formally quantified the relative contribution of each channel.

This paper complements but is distinct from Hoang et al. (2025), who examine forced relocation among the roughly 7,821 residents of Christchurch's Residential Red Zone using a binary natural experiment that holds earthquake exposure roughly constant. We instead exploit continuous spatial variation in seismic intensity across the much larger non-RRZ population (236,856 adults) to identify a dose-response relationship, and examine the underlying socioeconomic pathways, finding that employment disruption explains the effect for working-age adults but not the elderly (Section 6.4). The two papers together decompose the earthquake's mental health burden into the component from general seismic exposure (this paper) and from government-mandated displacement (Hoang et al., 2025).

This paper makes four contributions: (i) credible causal evidence on long-term mental health effects from comprehensive administrative panel data ($N = 236,856$; 2007–2019); (ii) a continuous, meshblock-level MMI treatment measure in a difference-in-differences framework with individual fixed effects that avoids the selection problems of survey-based studies; (iii) a rigorous, transparent treatment of the parallel trends assumption (Section 3.4), often glossed over in the disaster economics literature; and (iv)

evidence that employment disruption explains the mental health effect for working-age adults but not for the elderly – the most affected group (Section 6.4).

The findings indicate that increased earthquake intensity produces significant and lasting effects on mental health. Each unit increase in MMI raises psychiatric medication use by 0.051 medications per person-year (approximately 0.6 extra prescriptions annually), a 5.3% increase relative to the pre-earthquake control mean that persists for six to eight years. Because the MMI scale is not intuitive, we also express this per standard deviation: a one-SD increase in MMI ($SD = 2.08$) raises medication use by 0.107 medications per person-year, a 10.9% increase relative to the sample mean – broadly comparable to the 12% increase in mental disorder likelihood found by Liu et al. (2016) for typhoon exposure in Taiwan, though populations and outcomes differ.

Impacts are heterogeneous: adults aged 65+, individuals without tertiary education, and those with severe housing damage face substantially larger increases, with formal tests confirming these group differences are statistically significant (elderly vs. non-elderly: difference = 0.11, $p < 0.001$; no tertiary vs. tertiary: difference = 0.085, $p < 0.001$; severe vs. less-severe housing damage: difference = 0.103, $p = 0.020$). Point estimates are also larger for women than men (0.060 vs. 0.042), though this gap is not statistically significant ($p = 0.534$).

Mediation analysis shows employment disruption explains this pathway for working-age adults but not for the elderly, who bear the largest burden (Section 6.4); relocation contributes independently to depression outcomes. Hospital admissions for severe psychiatric conditions rise modestly (5.5%), consistent with the earthquake primarily generating mild-to-moderate rather than acute distress.

For broader context, Liu et al. (2016) find, using Taiwanese administrative records, that adults exposed to typhoons in utero face a 12% higher likelihood of adult mental disorder diagnosis – an early-life rather than direct-exposure effect. Karbownik and Wray (2019) similarly find that US males exposed to hurricanes in utero or infancy earn roughly 5% less as adults, attributed to reduced health capital. Neither study is directly comparable in population or outcome, but both benchmark the order of magnitude of disaster-induced health effects across contexts.

The closest comparison is Hoang et al. (2025), who study the same earthquake using the same IDI infrastructure and find an overall odds ratio of 1.22 for GP visits and medication prescriptions among Red Zone residents, rising to 2.48 among the elderly. We find a 5.3% increase in psychiatric medication use per unit of MMI across the much larger non-Red Zone population, persisting for six to eight years.

The remainder of the paper proceeds as follows. Section 2 describes the earthquake context; Section 3 presents data and methods; Section 4 reports main results; Section 5 presents robustness checks; Section 6 examines mediating pathways; Section 7 concludes.

2. The 2011 Christchurch earthquake

On 22 February 2011, Christchurch experienced a catastrophic earthquake with a moment magnitude of 6.2, epicentered on the Port Hills approximately 6 kilometers southeast of the central business district at a shallow depth of 5–6 kilometers. The event was part of the broader 2010–2011 Canterbury earthquake sequence, which began with the September 4, 2010 Darfield earthquake (Mw 7.1). The February 2011 event was particularly destructive due to its proximity to the city center, shallow focus, and exceptionally high peak ground accelerations – up to 2.2g vertically, among the highest ever recorded globally (Kaiser et al., 2012).

The earthquake caused 185 fatalities, over 8,000 injuries, and destroyed or severely damaged more than 100,000 buildings. Damage was concentrated in the CBD (multi-story buildings) and eastern suburbs (liquefaction), highly uneven across space due to soil composition, epicenter proximity, and pre-existing structural vulnerabilities. In response, the Canterbury Earthquake Recovery Authority classified areas as 'Red Zone' (severe damage; mandatory government buyout) or 'Green Zone' (suitable for rebuilding), shaping both physical recovery and population displacement as residents relocated from severely affected eastern suburbs to less-affected western and northern areas (Hoang & Noy, 2020, 2023, Hoang, 2022).

An important consideration is whether the September 2010 Darfield earthquake contaminates our treatment measure; a spatial correlation check confirms the two events' MMI footprints are statistically uncorrelated (Online Resource, Section F). Our preferred specifications nonetheless use 2007–2009 as the pre-period with 2010 as the reference year, excluding it from the pre-treatment window; results are stable whether or not 2010 is included (Section 5).

This study examines urban areas within Greater Christchurch, comprising Christchurch city and two adjoining districts, Waimakariri and Selwyn. We exclude Red Zone residential areas, subject to mandatory government buyout and relocation; mental health outcomes there are analyzed separately in Hoang et al. (2025). Figures 1 and 2 show the urban-rural classification and earthquake intensity map of the study region.

3. Data and methods

3.1 Data sources

Mental health data

We draw on three administrative data sources linked through New Zealand's Integrated Data Infrastructure (IDI): the pharmaceutical collection (subsidized prescription dispensing, from 2005; private-only care is rare, so any omission makes our estimates conservative – see Online Resource, Section B), the National Minimum Dataset (publicly funded hospital discharges), and Programme for the Integration of Mental Health Data- PRIMHD (publicly funded specialist services, available from July 2008).

Labor market and income data

We use individual-level tax return data covering the entire New Zealand working-age population, including monthly records of wages, self-employment income, and main government benefit receipt (industry classified per Australian and New Zealand Standard Industrial Classification -ANZSIC). We classify individuals annually into income quartiles based on total individual annual taxable income; 'low income' refers to the bottom quartile and 'high income' to the top quartile.

Earthquake exposure

Earthquake intensity is measured using USGS ShakeMap data, providing spatially interpolated MMI values at the meshblock level. MMI is an exogenously measured metric quantifying shaking severity based on observed effects on people and structures, making it less susceptible to reporting bias than self-reported exposure. Main models use continuous MMI values. For robustness, we also implement binary treatment-control designs using $MMI \geq 7$ – the standard New Zealand boundary between 'strong' and 'very strong' shaking, commonly associated with non-trivial structural damage – as the high-intensity threshold, and assess alternative cutoffs (≥ 6 , ≥ 8) with $MMI \leq 3$ as control (Section 5).

Housing damage data

Earthquake housing damage is measured using Earthquake Commission (EQC) insurance-assessed residential building damage costs, expressed as a percentage of property value at the meshblock level. Three levels are defined: no damage, less severe ($< 15\%$), and severe ($\geq 15\%$) – the latter threshold following EQC's operational classification for major structural repairs.

Demographic data

Demographic characteristics - age, gender, and ethnicity - are drawn from census data. Geographic classification of residential locations as urban or rural follows census-based criteria using population size and settlement characteristics. Geographic classification is available at the meshblock, Statistical Area 1 (SA1), SA2, SA3, territorial authority, and region levels¹.

3.2 Sample construction

We identify adults (≥ 18) residing in urban Greater Christchurch at the time of the earthquake, merging address histories with census urban-rural classifications. Minors are excluded, since prescription dispensing for children typically requires parental consent and follows distinct clinical pathways. We also exclude Red Zone residents, subject to mandatory government-managed relocation (analyzed separately in Hoang et al., 2025).

Individual addresses are matched to ShakeMap MMI values and meshblock-level housing damage. Mental health, tax, education, and demographic records are linked to construct a balanced panel. Our preferred specifications use 2007–2019, with three pre-earthquake years (2007–2009), nine post-earthquake years (2011–2019), with 2010 as the reference year. The full sample comprises 236,856 adults (2,844,672 person-year observations).

3.3 Descriptive statistics and balance

Table 1 presents descriptive statistics separately for the treatment group (MMI ≥ 7 , $n = 183,180$) and control group (MMI < 7 , $n = 53,676$). Both groups exhibit comparable gender distributions (48% male, 52% female) and similar average annual incomes (NZ\$26,743 vs. NZ\$26,191, statistically indistinguishable, $p = 0.37$). The control group is moderately older, with a larger share aged 65+ (23% vs. 20%) and a smaller share aged 18–29 (25% vs. 29%), and the treatment group has slightly higher pre-earthquake medication use (1.04 vs. 0.97), reflecting residential sorting by seismic risk zone rather than confounding. These modest compositional differences are fully absorbed by individual fixed effects, which control for all time-invariant characteristics including baseline mental health status; the identifying variation in our DiD estimator therefore comes from within-person changes over time across high- and low-intensity areas.

Table 1
Descriptive statistics by earthquake exposure group

Characteristic	Treatment (MMI ≥ 7) N = 183,180	Control (MMI < 7) N = 53,676	Full cohort N = 236,856	Difference (p-value)
Gender: Male	48%	48%	48%	0.0% (0.98)
Gender: Female	52%	52%	52%	0.0% (0.98)
Mean age (2011)	44	47	45	-3 (< 0.001)
Age: 18–29	29%	25%	28%	+ 4% (< 0.001)
Age: 30–44	27%	24%	26%	+ 3% (< 0.001)
Age: 45–64	25%	26%	25%	-1% (0.002)
Age: 65+	20%	23%	21%	-3% (< 0.001)
Tertiary education: Yes	63%	58%	61%	+ 5% (< 0.001)
Months non-employed, prior year (2010)	2.30	2.17	2.27 (SD:3.48)	+ 0.13 (< 0.001)
Months on benefits, prior year (2010)	1.51	1.27	1.46 (SD:3.6)	+ 0.24 (< 0.001)
Pre-earthquake medications	1.04	0.97	1.02 (SD:2.1)	+ 0.07 (< 0.001)
Annual income, 2010 (NZ\$)	26,743	26,191	26,618 (SD:27,599)	+ 552 (0.37)
Notes: Treatment group = MMI ≥ 7 at the 2011 earthquake; control group = MMI < 7 . Differences are mean differences (for continuous variables) or percentage-point differences (for proportions). P-values are from two-sample t-tests (continuous) or chi-square tests (proportions). Pre-earthquake medications refer to the average for 2007–2010.				

3.4 Empirical strategy and parallel trends

We employ a difference-in-differences (DiD) design exploiting spatial variation in earthquake intensity across meshblocks. Our baseline specification is:

$$Y_{ijt} = \alpha + \beta_1 * Post_t + \beta_2 * MMI_j(2011) + \beta_3 * (Post_t * MMI_j(2011)) + \delta_i + v_t + \beta_4 * X_{it} + \varepsilon_{ijt} \quad (1)$$

where Y_{ijt} is the per-person-year psychiatric medication count for individual i in meshblock j in year t . $Post_t$ equals one for years 2011 and later. $MMI_j(2011)$ is the continuous MMI value for meshblock j . The coefficient of interest β_3 captures how mental health outcomes changed after the earthquake as a function of local seismic intensity. Standard errors are clustered at the meshblock level.

Individual fixed effects δ_i control for time-invariant individual heterogeneity and year fixed effects v_t capture aggregate time trends. X_{it} includes age as the sole time-varying control, which enters as a deterministic cohort control and cannot be affected by earthquake exposure. Gender, education and ethnicity are treated as time-invariant characteristics and are fully absorbed by the individual fixed effects.

For dynamic effects, we replace $Post_t$ with a full set of year indicators:

$$Y_{ijt} = \alpha + \sum_t \beta_t (Year_t \times MMI_j(2011)) + \delta_i + v_t + \beta_4 X_{it} + \varepsilon_{ijt} \quad (2)$$

Parallel trends assessment.

The key identification assumption is that, absent the earthquake, mental health trends would have moved in parallel across high- and low-intensity areas. Three pieces of evidence support this: pre-earthquake event-study coefficients for 2007–2009 are close to zero and statistically insignificant (Fig. 3); formal joint F-tests fail to reject parallel trends for this window ($F = 0.73$, $p = 0.53$; Online Resource, Table A5); and the main coefficient is unchanged when individual-specific linear time trends are added (0.051 vs. 0.051), addressing concerns that such trends could overfit delayed treatment responses and corroborated by propensity-score matching (Online Resource, Section C).

A further consideration is the Stable Unit Treatment Value Assumption (SUTVA): if the control group experienced indirect disruption through city-wide demand shocks, our local estimates would be a lower bound, whereas resource redirection toward high-intensity areas could bias them upward. The alternative national control group (Table 9, Section 5.5) helps distinguish between these two possibilities directly: it yields a smaller coefficient than the local specification, consistent with mild spillover-driven attenuation of the local estimate rather than upward bias from resource redirection. Spatial placebo tests and coarser-level clustering provide additional, independent support for the robustness of our estimates (Online Resource, Section D)

4. Results

4.1 Average effects on psychiatric medication use

Table 2 presents estimates from Eq. (1), showing the average effect of earthquake intensity on psychiatric medication use over 2011–2019. Each unit increase in MMI raises overall medication use by 0.051 medications per person-year, a significant 5.3% increase relative to the pre-earthquake control mean of 0.97. The effect on mood disorders (depression and/or anxiety) is similar (0.048; 5.0%). Effects on anxiety alone and substance use are small and statistically insignificant, consistent with low pre-earthquake base rates.

Table 2
Main effects of earthquake intensity on psychiatric medication use

MMI x Post	All indicators	Mood disorders	Depression	Anxiety	Substance use
	0.051***	0.048***	0.021***	0.000	0.003
	(0.010)	(0.010)	(0.005)	(0.001)	(0.002)
Pre-earthquake mean (medications/person-year)	0.97	0.96	0.43	0.005	0.016
Percentage change	5.3%	5.0%	4.9%	-	-
Notes: Coefficients from Eq. (1), individual and year fixed effects. Standard errors (parentheses) clustered at meshblock level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Percentage change = (coefficient / pre-earthquake control group mean) x 100; shown only for significant estimates. Sample: 2007–2019, $N = 2,844,672$ person-year observations. Mood disorders = depression and/or anxiety.					

4.2 Heterogeneous effects by subgroup

Table 3 (Panel A) presents estimates from separate regressions for demographic and socioeconomic subgroups. Females exhibit a larger effect (0.060) than males (0.042); individuals without tertiary education face a substantially larger impact (0.098) than those with tertiary education (0.013); no significant effect is observed for adults under 65, while older adults (65+) experience the largest increase (0.147); low-income individuals show a significant effect (0.042) while high-income individuals do not; and housing damage amplifies the impact, with severe damage ($> 15\%$ of property value) yielding an effect of 0.139 versus 0.036 for less severe damage.

Table 3 (Panel B) formally tests whether these differences are statistically meaningful. The education gap (0.085), the elderly-versus-non-elderly gap (0.110), and the income gap (0.035) are all highly significant ($p < 0.001$); the severe-versus-less-severe housing damage gap (0.103) is significant at 5%. The gender gap (0.018) is directionally consistent but not significant ($p = 0.53$). These tests confirm the heterogeneous impacts reflect genuine group differences rather than sampling variation.

Table 3
Heterogeneous effects of earthquake intensity on psychiatric medication use *Panel A: Subgroup estimates*

Subgroup	All indicators	Mood disorders	Depression	Anxiety	Substance use
Gender: Female	0.060*** (0.013)	0.057*** (0.013)	0.027*** (0.007)	0.001 (0.001)	0.003 (0.003)
Gender: Male	0.042*** (0.010)	0.039*** (0.009)	0.015*** (0.005)	-0.000 (0.000)	0.003 (0.004)
Education: Tertiary	0.013 (0.008)	0.012 (0.007)	0.003 (0.004)	-0.000 (0.000)	0.000 (0.004)
Education: No tertiary	0.098*** (0.017)	0.091*** (0.017)	0.043*** (0.009)	0.001 (0.001)	0.006** (0.003)
Age: 18–29	0.007 (0.010)	0.010 (0.008)	0.004 (0.004)	0.001 (0.001)	-0.003 (0.005)
Age: 30–44	0.004 (0.014)	-0.008 (0.013)	0.000 (0.009)	-0.002 (0.001)	0.012* (0.006)
Age: 45–64	0.024 (0.015)	0.023* (0.014)	0.005 (0.009)	0.001 (0.001)	0.000 (0.004)
Age: 65+	0.147*** (0.024)	0.147*** (0.024)	0.062*** (0.013)	0.000 (0.001)	0.000 (0.001)
Income: Low (Q1)	0.042*** (0.009)	0.044*** (0.009)	0.018*** (0.006)	0.000 (0.000)	-0.002 (0.002)
Income: High (Q4)	0.007* (0.004)	0.008* (0.004)	0.002 (0.002)	-0.000 (0.000)	-0.000 (0.001)
Housing: Severe (>= 15%)	0.139*** (0.046)	0.087** (0.040)	0.012 (0.020)	-0.000 (0.004)	0.052*** (0.017)
Housing: Less severe (< 15%)	0.036** (0.015)	0.029** (0.014)	0.016* (0.009)	0.001 (0.001)	0.007* (0.004)
Notes: Each coefficient from an independent regression with individual and year fixed effects. Standard errors (parentheses) clustered at meshblock level. *** p < 0.01, ** p < 0.05, * p < 0.10. Mood disorders = depression and/or anxiety. Low income = first quartile; high income = fourth quartile. Sample: 2007–2019.					

Panel B: Tests of significant differences in treatment effects across subgroups

Comparison	Difference in coefficients	95% CI	P value
Female vs. male	0.018	[-0.021, 0.041]	0.534
No tertiary vs. tertiary education	0.085***	[0.038, 0.114]	< 0.001
Elderly (65+) vs. non-elderly (< 65)	0.110***	[0.063, 0.157]	< 0.001
Low income (Q1) vs. high income (Q4)	0.035***	[0.017, 0.059]	< 0.001
Severe housing damage vs. less severe	0.103**	[0.016, 0.196]	0.020
Notes: Differences are computed from seemingly unrelated regressions estimating both subgroup coefficients jointly. *** p < 0.01, ** p < 0.05, * p < 0.10.			

4.3 Event study: dynamic effects

Figures 3–8 report annual point estimates from Eq. (2) with 95% confidence intervals, using 2010 as the reference year and spanning 2007–2019. Pre-earthquake coefficients (2007–2009) are close to zero for most subgroups (Section 3.4). Medication use did not rise significantly in 2011 but increased sharply thereafter, remaining elevated for roughly six years before modestly declining after 2017 (Fig. 3) – a delayed pattern consistent with the lag between acute exposure and chronic psychological conditions and the gradual worsening of housing and employment situations.

Subgroup patterns (Figs. 4–8) mirror the main results: effects are larger and more persistent for females than males (Fig. 4); larger and more sustained for those without tertiary education (Fig. 5); concentrated almost entirely among adults 65+, peaking at 0.15–0.20 in 2016–2018, with minimal change for non-elderly individuals (Fig. 6); and notably delayed for housing damage, not rising until 2013–2014, consistent with the protracted EQC settlement process (Fig. 7). The low-income subgroup (Fig. 8) shows the most visible pre-2011 divergence of any group examined; this does not overturn the aggregate parallel-trends evidence (Section 3.4) but is addressed directly via propensity-score matching in Section 5.1.

4.4 Severe mental health: hospital admissions and specialist services

Table 4 presents effects on hospital admissions and specialist psychiatric service use. The overall coefficient is 0.001 ($p < 0.01$), a 5.5% increase from the low pre-earthquake baseline of 0.018 treatments per person-year. Only 0.8% of the cohort accessed such services over the study period (Online Resource, Table A2), confirming exposure primarily generates mild-to-moderate distress managed in primary care rather than acute crises. Older adults and those without tertiary education show the largest percentage increases (8.6% and 7.2%).

Table 4
Effects of earthquake intensity on severe mental health (hospital and specialist services)

Subgroup	Effect of earthquake (1)	Mean treatments pre-earthquake (2)	% Change (3)
All cohort	0.001*** (0.000)	0.018	5.5%
Female	0.001*** (0.000)	0.018	5.5%
Male	0.001*** (0.000)	0.018	5.5%
Tertiary education	0.0004 (0.000)	0.018	-
No tertiary education	0.0013*** (0.000)	0.018	7.2%
Age 18–29	0.0001 (0.000)	0.002	-
Age 30–44	0.0008 (0.001)	0.020	-
Age 45–64	0.0004 (0.001)	0.002	-
Age 65+	0.0018*** (0.001)	0.021	8.6%
Low income (Q1)	-0.000 (0.000)	0.010	-
High income (Q4)	0.0003 (0.000)	0.004	-
Notes: Each coefficient from an independent regression with individual and year fixed effects. Standard errors (parentheses) clustered at meshblock level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. % change = (coefficient ÷ mean) × 100. Percentage change shown only for significant estimates. Sample: 2007–2019.			

5. Robustness checks

5.1 Parallel trends

Extended pre-period and individual time trends

Table 5 reports coefficients with and without individual-specific linear time trends (see Section 3.4); the main coefficient (0.051) is unchanged across both specifications. Table 6 reports the corresponding Rambachan and Roth (2023) sensitivity analysis, showing our estimates remain meaningful under moderate assumed violations of parallel trends.

Table 5
Robustness to pre-period and individual time trends

Specification	All indicators	Mood disorders	Depression	Anxiety	Substance use
(1) Sample 2007–2019	0.051*** (0.010)	0.048*** (0.009)	0.021*** (0.005)	0.000 (0.000)	0.003 (0.002)
(2) Sample 2007–2019 + individual trends	0.051*** (0.010)	0.048*** (0.009)	0.021*** (0.005)	0.000 (0.000)	0.003 (0.002)

Notes: Each cell is the MMI x Post coefficient from Eq. (1). Individual trends = individual-specific linear time trends added to the specification. All regressions include individual and year fixed effects. Standard errors (parentheses) clustered at meshblock level. *** p < 0.01, ** p < 0.05, * p < 0.10. Reference year is 2010 in all specifications. Formal pre-trend F-tests (testparm) are reported in Table A5 of the Online Resource.

Honest DiD sensitivity analysis (Rambachan and Roth 2023)

Because failing to reject the pre-trend null does not guarantee parallel trends holds post-treatment, we follow Rambachan and Roth (2023) to assess how large a post-treatment violation – expressed as a multiple (M) of the largest pre-treatment violation – would be needed to overturn significance in each post-treatment year (methodology detailed in Online Resource, Section G). Table 6 reports the breakdown value M for each year.

Table 6
Relative magnitudes sensitivity analysis by post-treatment year (Rambachan and Roth (2023))

Year	Original 95% CI excludes zero (M = 0)	Breakdown value (M)
2011	No	—
2012	No	—
2013	Yes	0.00
2014	Yes	0.20
2015	Yes	0.20
2016	Yes	0.30
2017	Yes	0.30
2018	Yes	0.25
2019	Yes	0.20

Notes: Outcome is psychiatric medication count (all indicators, the main outcome in Table 2). Sensitivity analysis applies the relative-magnitudes restriction of Rambachan and Roth (2023) to the year-specific MMI x Year interaction coefficients from Eq. (2), with 2007–2009 as the pre-treatment window (2010 as reference year) and 2011–2019 as the post-treatment window. Breakdown values are computed on a grid with step size 0.025–0.05 and are reported to two decimal places.

Robustness follows a hump-shaped pattern: effects for 2011–2013 are not robust to any violation (M = 0), rising over 2014–2015 (M ≈ 0.20), peaking in 2016–2017 (M ≈ 0.30), and declining slightly through 2018–2019 (M ≈ 0.20–0.25). This mirrors the effect-magnitude trajectory in Section 4.3 – reassuringly, the years with the largest impacts are also the least sensitive to parallel-trends violations.

Not all subgroups satisfy parallel trends equally well – the low-income group shows some pre-trend (Fig. 8) – motivating the individual-trends check above. Propensity-score matching (Online Resource, Section C) yields closely consistent coefficients (0.0487, 0.053), and a Tobit model addressing the zero-inflated outcome (88.7% zeros) yields a consistent average marginal effect (0.042; Online Resource, Table A9).

5.2 Dose-response by MMI bins

Table 7 examines mental health effects across six MMI intensity categories (using MMI = 0 as baseline). Results confirm a clear dose-response relationship: effects generally increase with intensity, from 0.290 (all indicators) for MMI < 3.6 to 0.614 for MMI > 8.6, though the increase is not strictly monotonic (a modest dip occurs at the 5.6 ≤ MMI < 7.6 bin for the all-indicators and mood-disorders columns). The depression outcome, by contrast, rises monotonically across all six bins..

Table 7
Dose-response relationship: earthquake effects by MMI intensity category

MMI category (ref: MMI = 0)	All indicators	Mood disorders	Depression	Anxiety	Substance use	N (% of cohort)
0 < MMI < 3.6	0.290* (0.164)	0.332** (0.160)	0.137** (0.070)	-0.002 (0.007)	-0.042 (0.029)	2958 (1%)
3.6 <= MMI < 4.6	0.390*** (0.132)	0.434*** (0.127)	0.169*** (0.057)	-0.002 (0.006)	-0.044 (0.027)	30,801 (13%)
4.6 <= MMI < 5.6	0.467*** (0.152)	0.499*** (0.147)	0.191*** (0.069)	-0.009 (0.011)	-0.033 (0.030)	7,926 (3%)
5.6 <= MMI < 7.6	0.454*** (0.128)	0.487*** (0.123)	0.200*** (0.054)	-0.000 (0.006)	-0.033 (0.027)	79,806 (34%)
7.6 <= MMI < 8.6	0.528*** (0.129)	0.545*** (0.124)	0.231*** (0.054)	-0.002 (0.006)	-0.016 (0.028)	78,087 (33%)
MMI >= 8.6	0.614*** (0.138)	0.608*** (0.132)	0.236*** (0.059)	0.003 (0.007)	0.006 (0.036)	26,901 (11%)
Notes: Standard errors (parentheses) clustered at meshblock level. *** p < 0.01, ** p < 0.05, * p < 0.10. MMI = 0 is the baseline (no shaking; n = 10,377, 4%). Individual and year fixed effects included. Sample: 2007–2019. Mood disorders=depression and/or anxiety.						

5.3 Binary treatment analysis

As an alternative specification, we classify individuals as high- (MMI >= 7) or low-intensity (MMI < 7) and estimate intent-to-treat effects. Table 8 shows a treatment effect of 0.150 for all indicators (p = < 0.001), with the same subgroup pattern (largest effects for females, older adults, and those without tertiary education). Alternative cutoffs (>= 6, >= 8, vs. MMI <= 3 control) yield consistent coefficients ranging 0.507–0.557 (Online Resource, Table A3).

Table 8
Binary Treatment Analysis: Earthquake Effects (MMI >= 7 vs. MMI < 7)

Subgroup	All indicators	Mood disorders	Depression	Anxiety	Substance use
All cohort	0.150*** (0.036)	0.135*** (0.034)	0.064*** (0.019)	0.002 (0.002)	0.015* (0.008)
Female	0.163*** (0.052)	0.153*** (0.050)	0.083*** (0.027)	0.005 (0.004)	0.009 (0.011)
Male	0.136*** (0.040)	0.115*** (0.036)	0.044* (0.023)	-0.001 (0.001)	0.021 (0.013)
Tertiary education	0.029 (0.037)	0.019 (0.034)	0.021 (0.020)	-0.001 (0.002)	0.010 (0.012)
No tertiary education	0.291*** (0.065)	0.271*** (0.064)	0.113*** (0.034)	0.006 (0.004)	0.021* (0.012)
Age 18–29	0.009 (0.049)	0.011 (0.045)	0.022 (0.024)	0.003 (0.004)	-0.002 (0.016)
Age 30–44	-0.011 (0.061)	-0.060 (0.056)	0.023 (0.036)	-0.001 (0.006)	0.049** (0.023)
Age 45–64	0.049 (0.055)	0.047 (0.052)	-0.009 (0.035)	0.001 (0.003)	0.002 (0.015)
Age 65+	0.443*** (0.102)	0.444*** (0.101)	0.167*** (0.032)	0.004 (0.004)	-0.001 (0.002)
Low income (Q1)	0.098*** (0.038)	0.104*** (0.037)	0.016 (0.035)	-0.002 (0.001)	-0.005 (0.005)
High income (Q4)	0.018 (0.018)	0.023 (0.016)	0.014 (0.009)	-0.001 (0.001)	-0.005 (0.009)
Notes: Treatment = MMI >= 7; control = MMI < 7. Each row from an independent regression with individual and year fixed effects. Standard errors (parentheses) clustered at meshblock level. *** p < 0.01, ** p < 0.05, * p < 0.10.					

5.4 Spatial placebo tests

We randomly assign MMI values across meshblocks and re-estimate the main specification 1,000 times. Only 5.4% of iterations reach significance at the 5% level and 11.4% at the 10% level – closely matching the false-positive rate expected under chance. Our actual estimate (0.051, $p < 0.01$) lies well outside this placebo distribution (Online Resource, Table A8), confirming the observed effects are not an artifact of spatial assignment.

5.5 Alternative control group

Table 9 replicates the main analysis using all urban New Zealand residents outside Canterbury as the control group (~ 12.6 million person-years). This bears directly on SUTVA: if our local controls were mildly affected by the earthquake through city-wide demand shocks, their mental health would drift upward, attenuating our local estimate; if resource redirection biased us instead, the local estimate would be inflated.

The national control, insulated from Canterbury-specific spillovers, yields a smaller coefficient (0.014, $p < 0.01$) than the local specification (0.051), which is the pattern implied by mild spillover attenuation, not by resource-redirection inflation. We therefore read this gap as evidence that our preferred local estimate (0.051) is a conservative lower bound, not an inflated one, though some of the gap also reflects the national control's lower socioeconomic comparability as a counterfactual.

Table 9
Alternative control group: national urban comparison

Subgroup	Coefficient	Std. error	Observations
All cohort	0.014***	(0.003)	12,600,000
Female	0.016***	(0.004)	6,732,999
Male	0.011***	(0.004)	5,844,495
Tertiary education	0.013***	(0.003)	8,321,682
No tertiary education	0.015**	(0.006)	4,255,809
Age 18–29	0.017***	(0.004)	3,773,667
Age 30–44	0.019***	(0.006)	3,711,879
Age 45–64	0.007	(0.006)	3,518,184
Age 65+	0.015**	(0.007)	1,573,761
Low income (Q1)	0.012*	(0.006)	2,787,033
High income (Q4)	0.007***	(0.002)	2,697,624

Notes: Control group = all urban New Zealand residents outside Canterbury. Each row from an independent regression with individual and year fixed effects. Standard errors (parentheses) clustered at meshblock level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

6. Pathways from earthquake intensity to mental health

Having established the reduced-form effect, we now explore the pathways through which it may operate: housing damage (% of property value lost), non-employment duration (months without a job), benefit receipt duration, and residential relocation status (a change in meshblock of residence between 2010 and each subsequent year). We cannot observe relocation distance directly, as address histories are recorded at the meshblock rather than geocoded coordinate level; future work with geocoded addresses could quantify displacement distance more precisely.

Because the mediators are themselves post-earthquake outcomes, including them alongside MMI x Post risks the 'bad controls' problem (Angrist & Pischke, 2009); causal mediation in the sense of Imai et al. (2011) would require an instrument for each mediator, beyond the scope of the current data. The results below should therefore be read as descriptive evidence on which pathways are consistent with a mediating role, not as causal mechanism estimates – a limitation we return to in Section 6.4.

6.1 First-stage associations: earthquake intensity and potential mediators

Table 10 presents associations between earthquake intensity and each potential mediator. Each unit increase in MMI is associated with significantly higher housing damage (1.804 percentage points, $p < 0.001$), longer non-employment (0.018 months/year, $p < 0.01$), and higher relocation probability (0.002, $p < 0.10$). Benefit receipt shows no significant association, suggesting labor market displacement was not fully offset by welfare transfers.

The non-employment association is modest in absolute terms (0.018 months/year), but cumulates to roughly 0.14 additional months (4.5 days) over eight post-earthquake years per MMI unit. As shown below, even this modest increase is sufficient to absorb the direct MMI-mental health association in the pooled sample – though this pooled result masks important age-group heterogeneity, examined in Section 6.4.

Table 10
First-stage associations: earthquake intensity and potential mediators

MMI x Post	Housing damage (% prop. value)	Non-employment (months/year)	Benefit receipt (months/year)	Relocation (binary)
	1.804*** (0.041)	0.018*** (0.009)	0.010 (0.007)	0.002* (0.001)
Individual FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	2,621,250	2,086,377	478,962	2,838,000
Notes: Each column is an independent regression with individual and year fixed effects. Benefit months = main taxable benefits only. Standard errors in parentheses are clustered at the meshblock level. *** p < 0.01, ** p < 0.05, * p < 0.10.				

6.2 Descriptive mediation: single-mediator models

Table 11 examines each mediator separately alongside MMI x Post. Four patterns emerge: (i) including non-employment duration renders the MMI x Post coefficient statistically indistinguishable from zero across all indicators, consistent with joblessness playing a role in the pooled association; (ii) including relocation status, both MMI x Post and relocation independently predict outcomes, suggesting displacement contributes an additional channel; (iii) housing damage does not significantly reduce the MMI x Post coefficient, consistent with New Zealand's high residential insurance coverage (~ 95%) mitigating the immediate financial burden of property loss; and (iv) benefit receipt shows no mediating role.

These patterns should be interpreted cautiously as descriptive associations rather than causal effects. Conditioning on post-treatment mediators may introduce bias if they are affected by unobserved confounders correlated with both earthquake intensity and mental health outcomes.

Table 11
Descriptive mediation: single-mediator models

	All indicators			Mood disorders			Depression		
	Housing (1)	Jobless (2)	Reloc. (3)	Housing (4)	Jobless (5)	Reloc. (6)	Housing (7)	Jobless (8)	Reloc. (9)
<i>MMI × Post</i>	0.029**	0.002	0.044***	0.017	0.003	0.041***	0.009	−0.000	0.017***
	(0.014)	(0.005)	(0.009)	(0.013)	(0.004)	(0.008)	(0.009)	(0.003)	(0.005)
Housing damage	0.001			0.000			−0.003		
	(0.004)			(0.004)			(0.002)		
Jobless months		0.021***			0.019***			0.005***	
		(0.001)			(0.001)			(0.001)	
Relocation status			0.162***			0.165***			0.072***
			(0.024)			(0.019)			(0.011)
	Anxiety			Substance use					
	Housing (10)	Jobless (11)	Reloc. (12)	Housing (13)	Jobless (14)	Reloc. (15)			
<i>MMI × Post</i>	0.000	−0.000	0.000	0.012***	−0.001	0.003			
	(0.001)	(0.000)	(0.001)	(0.004)	(0.002)	(0.002)			
Housing damage	0.000			0.000					
	(0.000)			(0.001)					
Jobless months		0.000**			0.002***				
		(0.000)			(0.001)				
Relocation status			0.001			−0.002			
			(0.001)			(0.008)			
Observations	2,621,250	2,086,377	2,838,000	2,621,250	2,086,377	2,838,000	2,621,250	2,086,377	2,838,000
Notes: Each column is an independent regression with individual and year fixed effects. Standard errors in parentheses are clustered at the meshblock level. *** p < 0.01, ** p < 0.05, * p < 0.10.									

6.3 Joint mediation model

Table 12 includes all three mediators simultaneously. *MMI × Post* becomes statistically indistinguishable from zero across all outcomes in the pooled sample, while non-employment duration remains a significant predictor across all outcomes ($p < 0.01$ for four of the five indicators; $p < 0.05$ for anxiety), and relocation remains independently associated with depression specifically (0.011, $p < 0.05$). Housing damage remains insignificant. VIF for relocation and non-employment months is below 2, confirming no multicollinearity between mediators.

Taken together, these results are consistent with employment disruption linking seismic intensity to psychological distress in the pooled sample, with relocation contributing an additional channel for depression specifically. The absence of a direct housing damage association suggests property loss affects mental health indirectly – through labor market and social disruption – rather than through immediate financial distress, consistent with near-universal residential insurance coverage.

However, as Section 6.4 shows, this pooled result masks important age heterogeneity and should not be read as a unified mechanism operating across the population.

Table 12
Joint mediation model: All mediators simultaneously

Non-employment months	All indicators	Depression	Anxiety	Mood disorders	Substance use
	0.018*** (0.002)	0.004*** (0.001)	0.000** (0.000)	0.016*** (0.001)	0.002*** (0.001)
Relocation status	0.006 (0.013)	0.011** (0.006)	0.001 (0.001)	0.008 (0.012)	-0.002 (0.006)
MMI x Post	0.004 (0.004)	0.004 (0.002)	-0.001 (0.001)	0.003 (0.007)	0.003 (0.003)
Individual FE / Year FE	Yes / Yes	Yes / Yes	Yes / Yes	Yes / Yes	Yes / Yes
Notes: Non-employment months and relocation status are included simultaneously alongside housing damage, which is retained for completeness but is not a significant mediator. Individual and year fixed effects included in all specifications. Standard errors in parentheses are clustered at the meshblock level. *** p < 0.01, ** p < 0.05, * p < 0.10.					

6.4 Age-heterogeneous mechanisms

The pooled mediation results mask important heterogeneity across age groups. Recall from Section 4.2 that the effect of earthquake intensity is concentrated almost entirely among adults 65+ (coefficient 0.147, $p < 0.001$), with small, insignificant effects for working-age adults. We investigate this directly by estimating the first-stage and mediation models separately by age group, using age at the time of the earthquake as a fixed, pre-determined characteristic.

Table 13 presents the results. Panel A confirms the pattern from Section 4.2: the reduced-form mental health effect is large and significant for the elderly (0.147, $p < 0.001$) but small and insignificant for working-age adults (0.011).

Panel B shows the first-stage association between earthquake intensity and jobless months by age group. For working-age adults, the earthquake significantly increased joblessness (0.180 months/year, $p < 0.05$), confirming the employment disruption channel is operative. For adults 65+, the coefficient is small and insignificant (0.009), despite ~ 25% of this group being employed pre-earthquake – consistent with older workers exiting cleanly into New Zealand Superannuation-supported retirement rather than recorded non-employment, so jobless months does not fully capture labour market disruption for this group.

Panel C shows mediation results within each age group. Including jobless months alongside MMI x Post renders the direct earthquake coefficient statistically indistinguishable from zero in both groups, while jobless months remains a significant predictor throughout (0.037 for the elderly; 0.023 for working-age adults, both $p < 0.001$). For working-age adults this is consistent with employment disruption mediating the relationship, though the reduced-form effect is not itself significant, limiting what can be concluded strictly. For the elderly, the insignificant first stage means the full employment-disruption chain is not supported.

These results reveal two distinct patterns. Working-age adults experienced significant occupational disruption but no lasting population-level mental health deterioration, possibly reflecting partial buffering by Christchurch's post-earthquake construction boom. Adults 65+, by contrast, experienced large, persistent deterioration (0.147, $p < 0.001$) through pathways the observed mediators do not capture – most plausibly social network disruption, loss of community ties, neighbourhood destruction, and disrupted routine healthcare access, all particularly costly for older adults whose lives are more spatially rooted but unobservable in administrative records.

We treat this as an honest null result for the employment pathway among the elderly, not a secondary limitation. Because the elderly bear the largest mental health burden, the pooled mediation result identifies a channel operative specifically among working-age adults, not a general mechanism – implying differentiated policy: labor market interventions for working-age adults, and community-based social and healthcare support for older populations whose recovery pathways remain unobserved in administrative data.

Table 13
Age-heterogeneous mechanisms: mental health effects and employment disruption

Panel A: Mental health effect (reduced form)	Age 65+	Age < 65
MMI x Post	0.147*** (0.024)	0.011 (0.007)
<i>Panel B: Employment first stage</i>		
MMI x Post -> Jobless months	0.009 (0.019)	0.180** (0.068)
<i>Panel C: Mediation - including jobless months</i>		
MMI x Post	0.005 (0.013)	0.001 (0.005)
Jobless months	0.037*** (0.003)	0.023*** (0.002)
Notes: Each panel reports coefficients from independent regressions with individual and year fixed effects. Age group is defined by age at the time of the earthquake (2011), used as a fixed pre-determined characteristic. Standard errors in parentheses are clustered at the meshblock level. *** p < 0.01, ** p < 0.05, * p < 0.10. Sample: 2007–2019.		

7. Conclusion

This paper provides causal evidence that the 2011 Christchurch earthquake produced substantial and persistent mental health consequences for the affected urban population. Using a difference-in-differences design with individual fixed effects on administrative panel data linked across pharmaceutical, hospital, labor market, and tax records, we show that each unit increase in earthquake intensity raises psychiatric medication use by 5.3% (0.051 medications per person-year), persisting six to eight years post-disaster. Women, adults 65+, individuals without tertiary education, and those with severe housing damage bear a disproportionate, statistically confirmed share of the burden. A central methodological contribution is our transparent treatment of the parallel trends assumption (Section 3.4), which substantially strengthens confidence in the causal interpretation.

On the question of mechanisms, employment disruption explains the pathway for working-age adults but not for the elderly, who bear the largest mental health burden (Section 6.4). These findings call for differentiated recovery policies. For working-age adults, rapid re-employment and job-matching services may limit psychological harm from occupational disruption. For older populations, who face the greatest and most persistent burden, effective intervention requires community-based support, social infrastructure investment, and sustained primary healthcare access rather than labor market programs alone.

The study also clarifies the nature of the burden: exposure primarily generates mild-to-moderate distress managed through primary care rather than severe crises requiring hospitalization - the additional medication use (0.051 per person-year) is roughly 50 times larger in absolute terms than the additional hospital/specialist treatment (0.001 per person-year), and only 0.8% of the cohort ever accessed such services over the 13-year study period.

Several limitations warrant acknowledgment. Administrative data may not capture all dimensions of psychological well-being, such as grief or subclinical distress that never reaches a prescription. Supply-side healthcare disruptions may have constrained early access to care, making our estimates – particularly for the first one to two years – conservative lower bounds. Parallel trends may not hold perfectly for all subgroups, particularly the lower-education group, though our checks mitigate this. Finally, generalizability from New Zealand's near-universal insurance and safety net to lower-income disaster-prone settings remains an open question.

Despite these limitations, internal validity is supported by null placebo tests, monotonic dose-response patterns, coefficient stability across specifications, and consistency across alternative control groups. The results contribute to the literature on the economic and social costs of natural disasters and offer a foundation for recovery policies that integrate differentiated labor market and community support targeting the most vulnerable groups.

Declarations

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Ethics approval: The results in this paper are not official statistics. They have been created for research purposes from the Integrated Data Infrastructure (IDI) managed by Statistics New Zealand under the Statistics Act 1975 and Tax Administration Act 1994. The opinions, findings, recommendations, and conclusions expressed are those of the author and not Statistics NZ.

Data availability: This research uses Integrated Data Infrastructure (IDI) data managed by Statistics New Zealand. The results are not official statistics. Access to the anonymised data was provided by Statistics New Zealand under the Statistics Act 1975 and Tax Administration Act 1994. Data are available to approved researchers through Statistics New Zealand's secure data lab.

Author Contribution

T.H. designed the study, performed the data analysis, prepared all figures and tables, and wrote the manuscript.

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Data Availability

This research uses Integrated Data Infrastructure (IDI) data managed by Statistics New Zealand. The results are not official statistics. Access to the anonymised data was provided by Statistics New Zealand under the Statistics Act 1975 and Tax Administration Act 1994. Data are available to approved researchers through Statistics New Zealand's secure data lab.

References

1. Akram, S., Baloch, M.Y.J., Alrefaei, A.F., Almutairi, M.H., Idrees, M., Al-Kubaisi, H.A.R.: Interface between mental health and the earthquake: Considering humanitarian endeavor. *Front. Public. Health.* **12**, 1326407 (2024). <https://doi.org/10.3389/fpubh.2024.1326407>
2. Angrist, J.D., Pischke, J.S.: Mostly harmless econometrics: An empiricist's companion. Princeton University Press (2009). <https://doi.org/10.1515/9781400829828>
3. Bai, Y., Li, Y.: More suffering, more involvement? The causal effects of seismic disasters on social capital. *World Dev.* **138**, 105221 (2021). <https://doi.org/10.1016/j.worlddev.2020.105221>
4. Cameron, A.C., Miller, D.L.: A Practitioner's Guide to Cluster-Robust Inference. *J. Hum. Resour.* **50**(2), 317–372 (2015). <https://doi.org/10.3368/jhr.50.2.317>
5. Davidson, J.R., Hughes, D., Blazer, D.G., George, L.K.: Post-traumatic stress disorder in the community: an epidemiological study. *Psychol. Med.* **21**(3), 713–721 (1991). <https://doi.org/10.1017/s0033291700022352>
6. De, P.K., Thamarapani, D.: Impacts of negative shocks on wellbeing and aspirations—Evidence from an earthquake. *World Dev.* **154**, 105876 (2022). <https://doi.org/10.1016/j.worlddev.2022.105876>
7. Galea, S., Nandi, A., Vlahov, D.: The epidemiology of post-traumatic stress disorder after disasters. *Epidemiol. Rev.* **27**(1), 78–91 (2005). <https://doi.org/10.1093/epirev/mxi003>
8. Harada, N., Shigemura, J., Tanichi, M., Kawaida, K., Takahashi, S., Yasukata, F.: Mental health and psychological impacts from the 2011 Great East Japan Earthquake Disaster: a systematic literature review. *Disaster military Med.* **1**(1), 17 (2015). <https://doi.org/10.1186/s40696-015-0008-x>
9. Hoang, T.: *Essays on Disaster Risk Management and Policy in New Zealand* (Doctoral dissertation, Open Access Te Herenga Waka-Victoria University of Wellington). (2022)
10. Hoang, T., Noy, I.: Wellbeing after a managed retreat: Observations from a large New Zealand program. *Int. J. Disaster Risk Reduct.* **48**, 101589 (2020). <https://doi.org/10.1016/j.ijdr.2020.101589>
11. Hoang, T., Noy, I.: The income consequences of a managed retreat. *Reg. Sci. Urban Econ.* **100**, 103896 (2023). <https://doi.org/10.1016/j.regsciurbeco.2023.103896>

12. Hoang, T., Noy, I., Van, T.L.: Heterogenous mental health impacts of a forced relocation: The red zone in Christchurch (New Zealand). *Health Econ.* **34**(10), 1782–1803 (2025). <https://doi.org/10.1002/hec.70004>
13. Imai, K., Keele, L., Tingley, D., Yamamoto, T.: Unpacking the black box of causality: Learning about causal mechanisms from experimental and observational studies. *Am. Polit. Sci. Rev.* **105**(4), 765–789 (2011). <https://doi.org/10.1017/s0003055411000414>
14. Jia, Z., Tian, W., Liu, W., Cao, Y., Yan, J., Shun, Z.: Are the elderly more vulnerable to psychological impact of natural disaster? A population-based survey of adult survivors of the 2008 Sichuan earthquake. *BMC public. health.* **10**(1), 172 (2010). <https://doi.org/10.1186/1471-2458-10-172>
15. Kaiser, A., Holden, C., Beavan, J., Beetham, D., Benites, R., Celentano, A., Zhao, J.: The Mw 6.2 Christchurch earthquake of February 2011: preliminary report. *NZ J. Geol. Geophys.* **55**(1), 67–90 (2012). <https://doi.org/10.1080/00288306.2011.641182>
16. Karbownik, K., Wray, A.: Long-run consequences of exposure to natural disasters. *J. Labor Econ.* **37**(3), 949–1007 (2019). <https://doi.org/10.1086/702652>
17. Kessler, R.C.: Posttraumatic stress disorder: the burden to the individual and to society. *J. Clin. Psychiatry.* **61**, 4–14 (2000)
18. Kirchberger, M.: Natural disasters and labor markets. *J. Dev. Econ.* **125**, 40–58 (2017). <https://doi.org/10.1016/j.jdeveco.2016.11.002>
19. Liu, E.M., Liu, J.T., Tseng, T.Y.H.: Fetal origins of mental health: Evidence from natural disasters in Taiwan. *Unpublished manuscript, Department of Economics, University of Houston.* (2016)
20. Ministry of Health New Zealand: Mental Health and Addiction Data. Wellington: Ministry of Health. (2023). <https://www.health.govt.nz/statistics-research/statistics-and-data-sets/mental-health>
21. Norris, F.H. (ed.): *Methods for disaster mental health research.* Guilford Press (2006)
22. Paudel, J., Ryu, H.: Natural disasters and human capital: The case of Nepal's earthquake. *World Dev.* **111**, 1–12 (2018). <https://doi.org/10.1016/j.worlddev.2018.06.019>
23. Paudel, P., Sah, A., Khanal, A.: Posttraumatic stress disorder and associated factors in the aftermath of the 2015 earthquake in Nepal: A systematic review and meta-analysis. *Plos one.* **20**(2), e0310233 (2025). <https://doi.org/10.1371/journal.pone.0310233>
24. Raker, E.J., Lowe, S.R., Arcaya, M.C., Johnson, S.T., Rhodes, J., Waters, M.C.: Twelve years later: The long-term mental health consequences of Hurricane Katrina. *Soc. Sci. Med.* **242**, 112610 (2019). <https://doi.org/10.1016/j.socscimed.2019.112610>
25. Rambachan, A., Roth, J.: A more credible approach to parallel trends. *Rev. Econ. Stud.* **90**(5), 2555–2591 (2023). <https://doi.org/10.1093/restud/rdad018>
26. Shidiqui, K.A., Di Paolo, A., Choi, Á.: *Earthquake exposure and schooling: impacts and mechanisms*(No. 202206). University of Barcelona, Research Institute of Applied Economics. (2022). <https://doi.org/10.1016/j.econedurev.2023.102397>

Footnotes

1. Meshblocks are the smallest geographic unit used by Stats NZ, each containing approximately 30–60 residents; Statistical Areas (SA1, SA2, SA3) are successively coarser aggregations of meshblocks, with SA2 broadly corresponding to a suburb or locality; Territorial Authorities (TAs) correspond to city or district councils (e.g., Christchurch City); and Regions are the coarsest level (e.g., Canterbury). New Zealand has approximately 53,000 meshblocks, 2,200 SA2s, 67 TAs, and 16 regions.

Figures

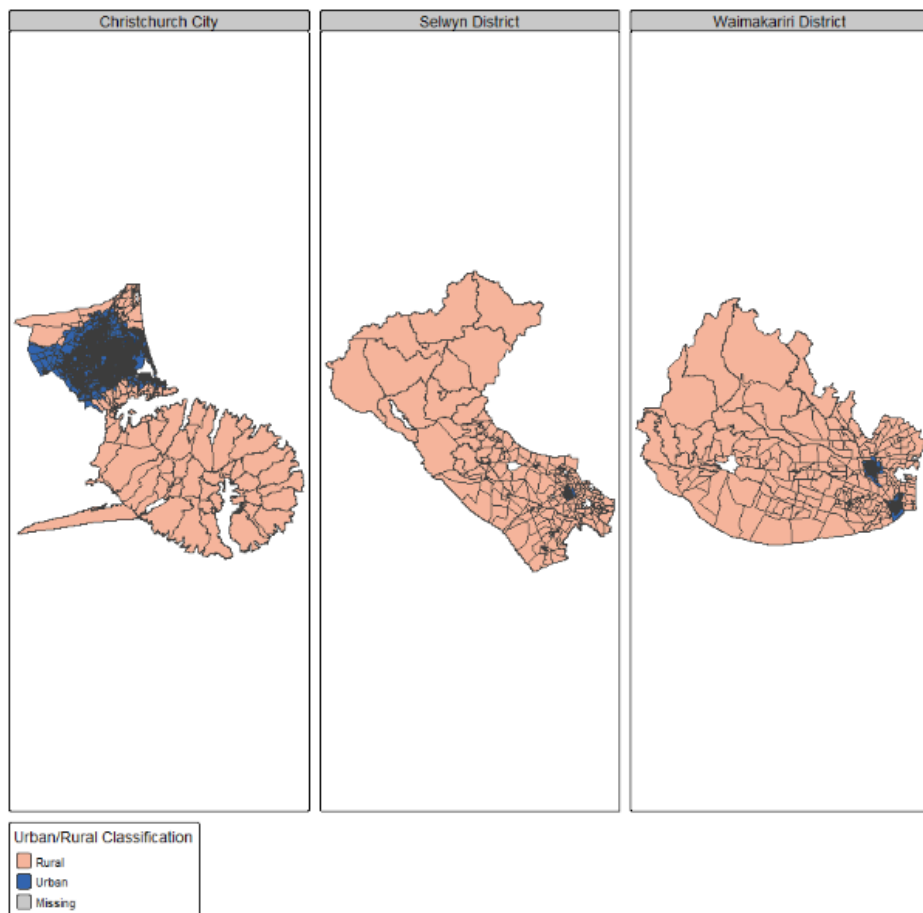


Figure 1

Urban and rural classification in Greater Christchurch

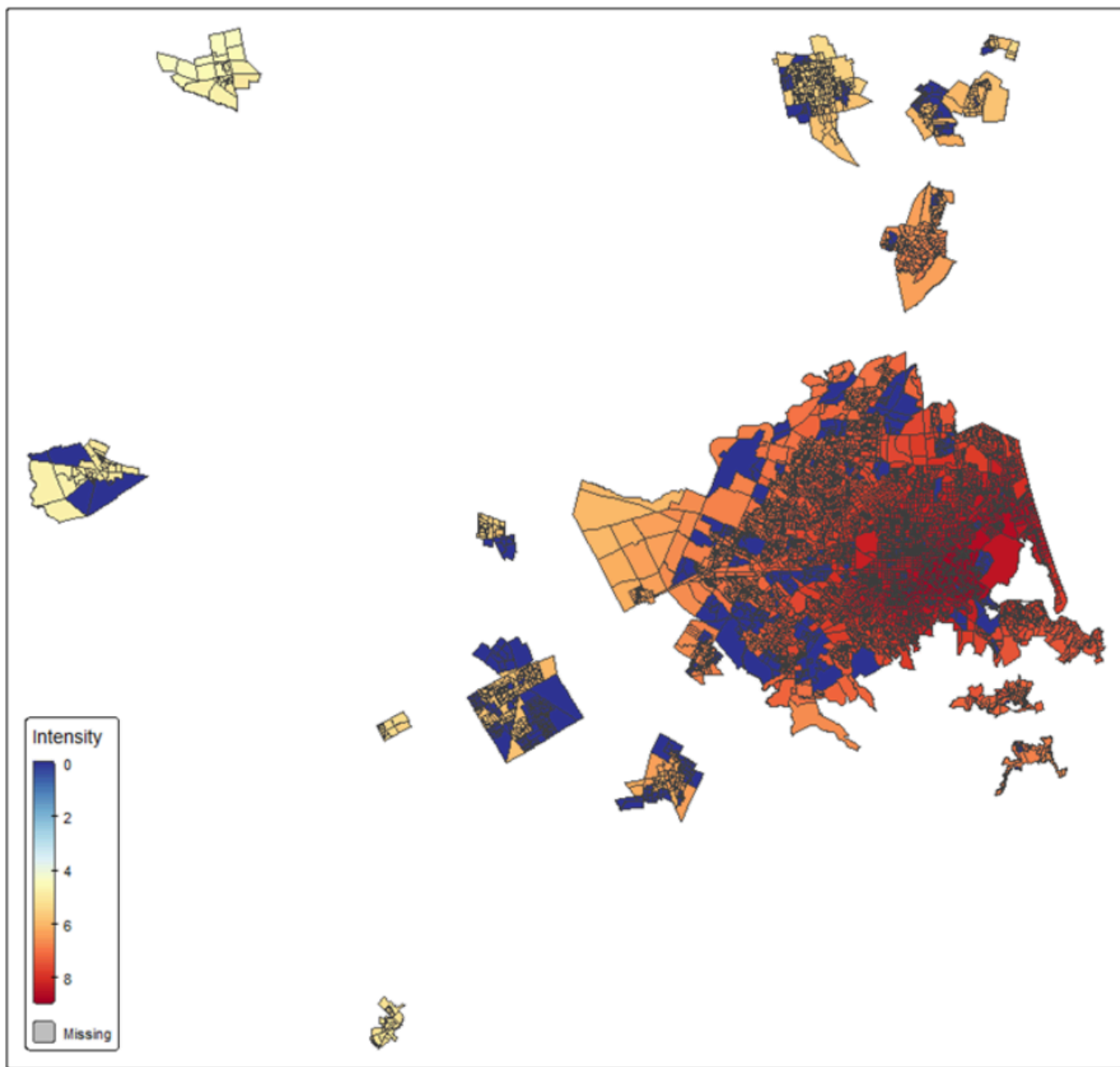


Figure 2

Greater Christchurch urban area and earthquake intensity (MMI)

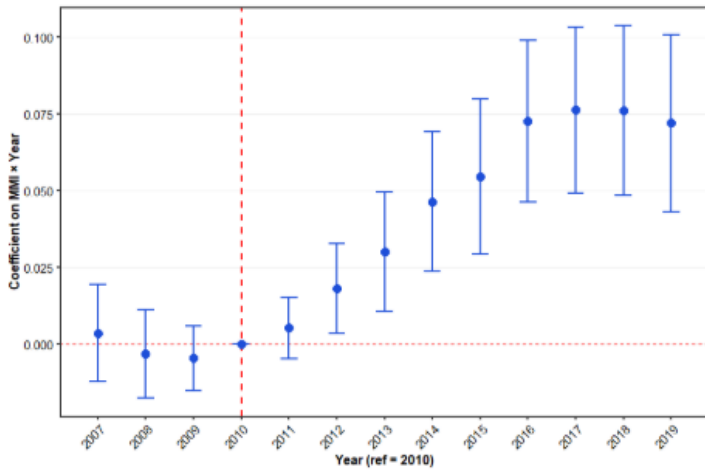


Figure 3

Event study - All cohort (2007-2019), Outcome: All indicators

Notes: Annual MMI x Year interaction coefficients from equation (2), 2007-2019 sample, 2010 reference year. The pre-earthquake coefficients for 2007-2009 are close to zero and statistically insignificant, supporting parallel trends. Standard errors clustered at meshblock level.

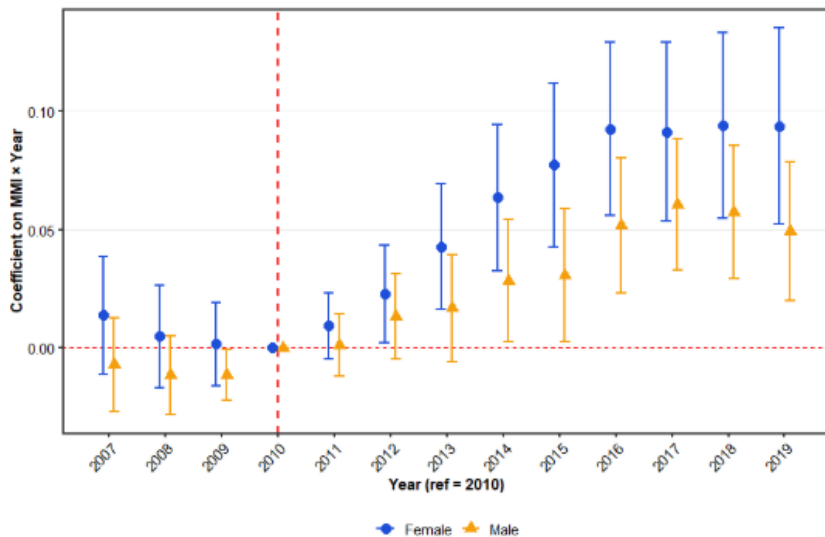


Figure 4

Event study by gender - Female vs. Male (2007-2019)

Notes: Annual MMI x Year interaction coefficients estimated separately for female and male subgroups. Pre-earthquake coefficients are close to zero for both groups in 2007-2009, supporting parallel trends. Standard errors clustered at meshblock level.

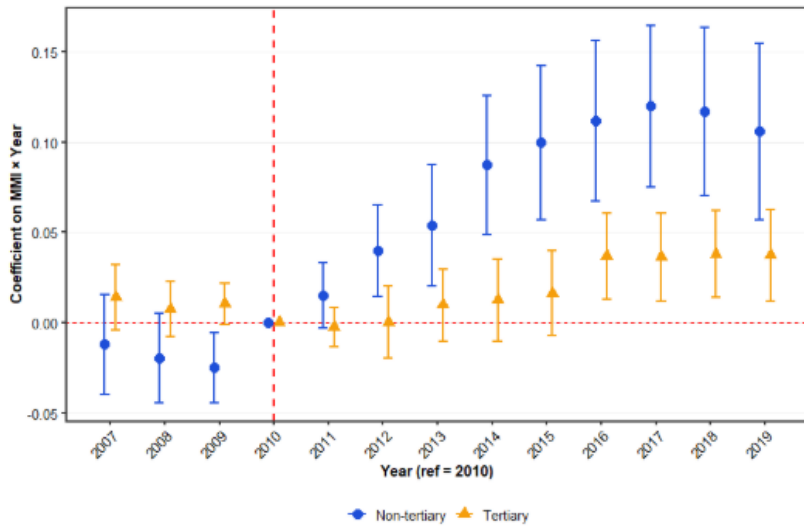


Figure 5

Event study by education - Tertiary vs. Non-Tertiary (2007-2019)

Notes: Annual MMI x Year interaction coefficients estimated separately for tertiary-educated and non-tertiary-educated individuals. Standard errors clustered at meshblock level.

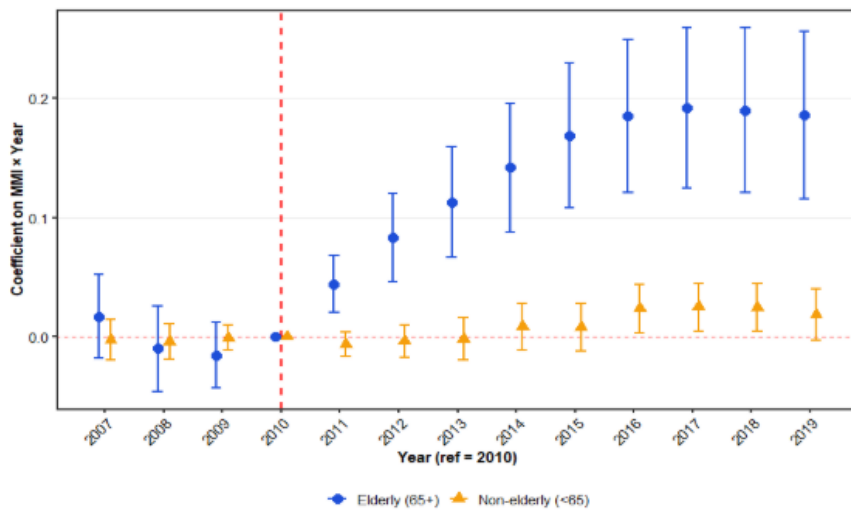


Figure 6

Event study by age - elderly (65+) vs. non-elderly (2007-2019)

Notes: Annual MMI x Year interaction coefficients estimated separately for adults aged 65 and older (elderly) and those under 65 (non-elderly). Standard errors clustered at meshblock level.

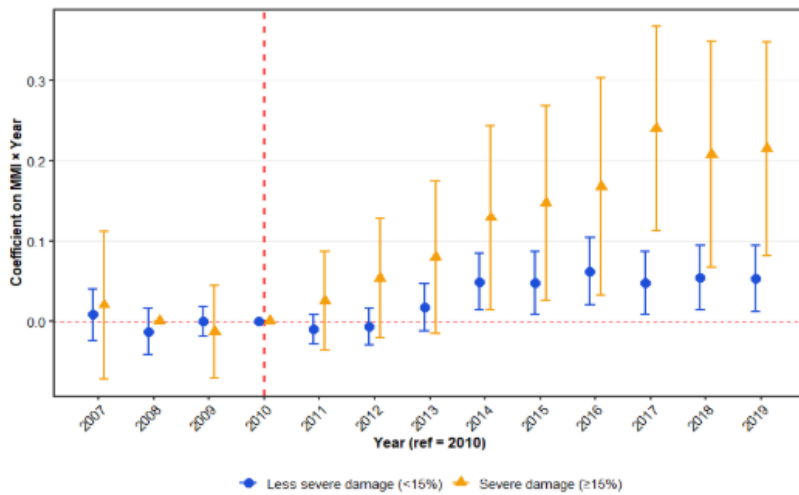


Figure 7

Event study by housing damage - severe ($\geq 15\%$) vs. less severe ($< 15\%$)

Notes: Annual MMI x Year interaction coefficients estimated separately for individuals in areas with severe housing damage ($\geq 15\%$ of property value) and less severe damage ($< 15\%$). Standard errors clustered at meshblock level.

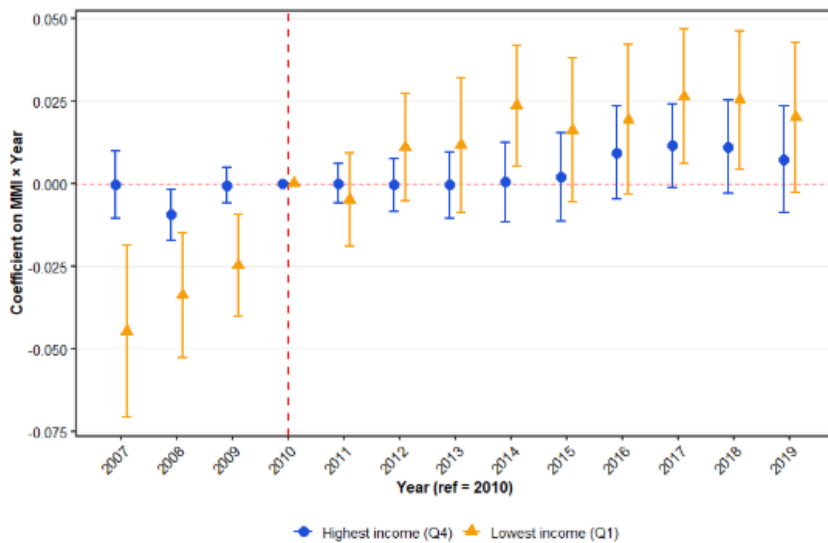


Figure 8

Event study by income - lowest (Q1) vs. highest (Q4) income quartile (2007-2019)

Notes: Annual MMI x Year interaction coefficients estimated separately for individuals in the lowest (Q1) and highest (Q4) individual annual income quartiles. Standard errors clustered at meshblock level.

Relative-Magnitudes Breakdown Values by Post-Treatment Year
(Rambachan and Roth 2023)

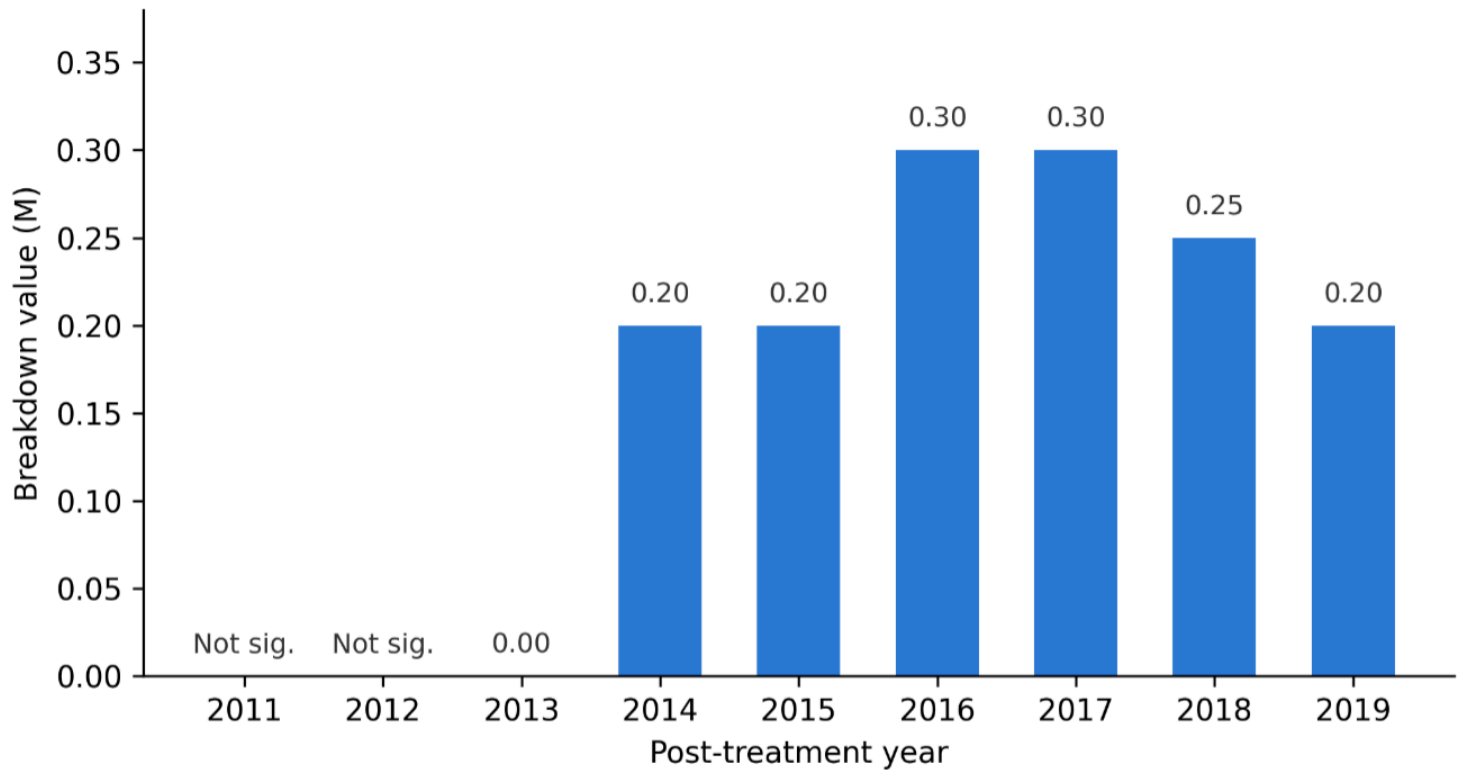


Figure 9

Relative-magnitudes breakdown values (M) by post-treatment year, corresponding to Table 6.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [paperEJHEOnlineResource.docx](#)