

Maternal Stress and Birth Outcomes: Evidence from an Unexpected Earthquake Swarm*

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July 2019

Preliminary, please do not circulate or cite without the authors' permission

Abstract

We examine the impact of a major earthquake that unexpectedly affected the Canterbury region of New Zealand on a wide-range of birth outcomes, including birth weight, gestational age and an indicator of general newborn health. We control for observed and unobserved differences between pregnant women in the area affected by the earthquake and other pregnant women by including mother fixed effects in all of our regression models. We extend the previous literature by comparing the impact of the initial unexpected earthquake to the impacts of thousands of aftershocks that occurred in the same region over the 18 months following the initial earthquake. We find that exposure to these earthquakes reduced gestational age, increased the likelihood of having a late birth and negatively affected newborn health - with the largest effects for earthquakes that occurred in the first and third trimester of pregnancy. Our estimates are similar when we focus on just the impact of the initial earthquake or, in contrast, on all earthquakes controlling for endogenous location decisions using an instrumental variables approach. This suggests that the previous estimates in the literature that use this approach are likely unbiased and that treatment effects are homogenous in the population. We present supporting evidence that the likely channel for these adverse effects is maternal stress.

Keywords: Maternal stress, pregnancy, earthquakes, birth weight, Apgar score

JEL: I12; J13; I31

* We thank Victoria Larsen and Liang Yun as well as seminar participants at Princeton University, the University of New Hampshire, and the University of Canterbury and conference participants at the New Zealand Association of Economists meeting. Neither author received any funding for this research.

I. Introduction

A number of recent studies have found that experiencing traumatic events during pregnancy and, more generally, being in poor mental health while pregnant has significant adverse consequences on the birth outcomes of the offspring.¹ In general, these papers find that stress either early or late in the pregnancy (i.e. in the first or third trimester) typically has negative impacts on gestational length and child birthweight, with stress during early pregnancy having especially detrimental effects.² Early life conditions, in turn, have been shown to have significant impacts on later life health and socio-economic outcomes and even on mortality (Almond and Currie 2011; Van den Berg, et al. 2006; Torche 2018).

There are two key identification challenges that need to be overcome in this literature. The first is to isolate the effects of stress from other consequences of a particular stress inducing event. For example, natural disasters may directly impact maternal health by changing the resources and infrastructure available to pregnant women and their families. Similarly, the death of a family member likely has direct impacts on family resources. The second is to deal with the potential endogeneity or predictability of a stressful event. For many of the events previously studied, people are likely to have some information about their susceptibility to the event and make life choices accordingly. This type of selection likely occurs along dimensions that also matter for health outcomes. For example, individuals who are better at dealing with stress might be more willing to live in flood or earthquake-prone areas, or to remain in cities that are more likely to be targeted by terrorists. Even if an event is by definition exogenous, e.g. an earthquake, if there are heterogeneous treatment effects, previous residential sorting might lead to an understatement of the average impact of exposure to this event on birth outcomes, assuming that people who are likely to experience the largest treatment effects are those who sort into locations less likely to experience a particular event.³

¹ For example, Aizer et al. (2016) and Carney (2016) examine the impact of general stress and mental health problems; Black et al. (2016) and Persson and Rossin-Slater (2017) look at the impact of stress caused by a death in the family; Brown (2014), Camacho (2008) Eccleston (2011), Lee (2014), Mansour and Rees (2012), and Quintana-Domeque and Ródenas-Serrano (2014) look at stress caused by terrorist attacks and other domestic armed conflicts; Carlson (2014; 2015) look at stress caused by bad economic news; and Currie and Rossin-Slater (2013), Simeonova (2011), Tan et al. (2009) and Torche (2011) look at stress caused by natural disasters.

² Studies that directly measure prenatal stress with levels of the hormone cortisol (e.g., Aizer et al. 2016) confirm that this biological mechanism can directly impact birth outcomes.

³ Boes et al. (2013) finds evidence of this type of sorting in regards to the impact of noise pollution on individual health.

The previous papers in this literature take various approaches to deal with these two issues, but typically it is difficult to find an event that is both a total surprise and unlikely to directly impact resources for pregnant women and their families. In this paper, we are arguably able to do this. We examine the impact of a major earthquake that unexpectedly affected the Canterbury region of New Zealand – and its pregnant residents – on September 4, 2010. This earthquake occurred on a previously unknown fault line and as such caught people across the whole demographic and socio-economic spectrum by surprise⁴. The genuine lack of information about earthquake risk prevented any residential sorting along this dimension. Additionally, this earthquake caused surprisingly little damage given its large size (magnitude of 7.1) and its proximity to Christchurch, the second largest city in New Zealand and largest on the South Island.⁵ Furthermore, New Zealand has a public health system with free provision of both pre- and post-natal care and, as we discuss in more detail below, there was little impact of this earthquake on health facilities.

Our initial analysis examines the impact of this earthquake on all women who were already pregnant when it occurred. We have access to the full universe of birth records from 2003 to 2012 and can identify mothers who gave birth multiple times in this period. This allows us to control for unobserved differences between pregnant women in the area affected by the earthquake and other pregnant women in different locations and time-periods by including mother fixed effects in all of our regression models. Effectively, this approach takes previously-born children of the same mother as the counterfactual for what the birth outcomes for the affected child would have been if the earthquake has not happened while the mother was pregnant with this child. Using this approach, we examine the impact of this unexpected earthquake (and its associated aftershocks) on a wide range of birth outcomes, including birth weight, gestational age and general newborn health (measured by the 5-minute Apgar score

⁴ GNS geologist Simon Cox said the following in an interview for the NZ Herald a day after the main shock: "There is no evidence at this site for previous rupture. We don't think it has ruptured often, or at all, in the last 18,000 years." (from NZ Herald article "New faultline comes as big surprise to scientists"; Accessed 11/12/2018 at: https://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=10671382)

⁵ Specifically, the initial earthquake caused no deaths and only two serious injuries – partly due to reinforced housing mandatory in New Zealand and partly due to the quake's occurrence at 4:35am when most residents were off the street.

and whether the child was delivered by a caesarean section), allowing for the impact to depend on the trimester of the pregnancy at the time of the earthquake.⁶

The September 2010 Canterbury earthquake was followed by almost eighteen months of strong, persistent aftershocks. Between September 4, 2010 and May 25, 2012 there were 46 earthquakes with a magnitude greater than 5, the level where earthquakes are typically strongly felt, on the same fault line. Obviously, women who became pregnant after September 4, 2010, did this with the knowledge that there could potentially be more earthquakes in the future although without being able to know how many and their timing.

The existence of these aftershocks allows us to extend the previous literature in three dimensions. First, we use the best practice methodology for accounting for residential sorting and selection to produce consistent estimates of the impacts of all of the earthquakes that occurred in the Canterbury region between September 4, 2010 and May 25, 2012 on birth outcomes regardless to when the child was conceived. Specifically, we follow Currie and Rossin-Slater (2013) and instrument for each pregnant woman's actual exposure to earthquakes in each trimester of her pregnancy with the exposure she would have experienced based on her residential choice when previously pregnant before the initial earthquake.⁷ We then compare the estimates obtained using this approach to the initial estimates that focus just on women already pregnant when the first earthquake occurred. This allows us to jointly evaluate the validity of the more general approach and whether, in our application, there is no selection into pregnancy after the initial earthquakes related to heterogenous treatment effects.

Second, because the Canterbury region experienced such a large number of earthquakes, we can examine whether the intensity of exposure to stress in different trimesters has differential impacts on birth outcomes. In particular, we compare results where we measure the intensity of exposure using i) the total energy of the earthquakes experienced during a particular trimester of the pregnancy, ii) whether any large earthquakes were experienced during a particular trimester; and iii) the number of days during a particular trimester where large

⁶ We also follow the previous literature, for example Currie and Rossin-Slater (2013), and use an instrumental variables approach to adjust our estimates of the impact of third trimester exposure to stress to account for the impact of stress on gestational length. This approach creates an instrument for actual third trimester exposure that assumes that this trimester last exactly 93 days for all births and calculates exposure for this fixed period of time.

⁷ We also adjust these estimates for the endogenous length of third trimester exposure as described in the previous footnote.

earthquakes were experienced. This allows us to evaluate whether persistent stress has different impacts on pregnancies compared to large one-off exposure to stress.

Third, we directly examine selection into pregnancy after the initial earthquake as well as residential sorting. Specifically, we examine whether the characteristics of pregnant women affected by the earthquakes differ for births conceived after September 4, 2010 compared to those conceived prior to the initial earthquake. We also examine whether the characteristics of women who conceived after the initial earthquake outside of the affected areas of Canterbury but who had previously given birth in the affected areas differ from those who also moved away from Canterbury between births that were conceived prior to the initial earthquake. These two comparisons allow us to categorize the type of selection and sorting that is quite likely to occur in other contexts as well.

We also allow for heterogeneity in the impact of these earthquakes along two observable dimensions. The first is the degree of direct damage that the initial earthquake and its aftershocks caused in different areas of Canterbury. This allows us to examine whether the main channel for any impacts is likely to be something other than an increase in stress. The second is the mother's age. Here, we are specifically interested in testing whether earthquake induced maternal stress has a larger impact on more vulnerable mothers (i.e. younger and older mothers).

Consistent with the literature, we find evidence that exposure to the Christchurch earthquakes reduced gestational age, increased the likelihood of having a late birth and negatively affected newborn health - with the largest effects for earthquakes that occurred in the first and third trimester of pregnancy. Our estimates are similar when we focus on just the impact of the initial earthquake or, in contrast, on all earthquakes controlling for endogenous location decisions using an instrumental variables approach. This is true even though the observable characteristics of these women differ. This suggests that the previous estimates in the literature that use this approach are likely unbiased and that treatment effects are homogenous in the population.

In general, we find similar results whether we categorize earthquake exposure by total energy, experiencing any large (magnitude 5 or greater) earthquakes or the number of days during a trimester experiencing large earthquakes. The main exception is that large earthquakes

experienced in the third trimester have negative impacts on newborn health while merely having exposure to a greater number of smaller earthquakes does not.

When we allow impacts to vary depending on how much damage occurred in each neighbourhood in Christchurch, we find no evidence of heterogenous impacts. This suggests that stress caused by the earthquakes rather than reduced infrastructure or direct impacts on individuals was the main channel leading to negative effects on children. On the other hand, when we allow the impacts to vary by mother's age, we find larger negative effects on teenage mothers, who are already more likely to experience poor birth outcomes.

II. Background

The 2010 Canterbury Earthquake

Our earthquake data come from GeoNet, a geological hazard monitoring system in New Zealand.⁸ Figure 1 shows the pattern of earthquakes over time in the Greater Christchurch area, which comprises three Territorial Local Authorities of the Canterbury region: Christchurch City, Selwyn, and Waimakariri (Figure A1. in the Appendix; we refer to this as the 'affected' area in the remainder of the paper). While very small earthquakes occur often in Canterbury, as well as the rest of New Zealand, only four moderate earthquakes (those with a magnitude between 5 and 6) occurred in the 10 years prior to the 2010 earthquake and these were all on a different faultline further from main population centres in the area.

The main shock of the Canterbury earthquake occurred on September 4, 2010 at 4:35 am. The quake had a moment magnitude of 7.1 and was shallow. The epicentre was inland, about 40 kilometres (25 miles) west of Christchurch, New Zealand's second largest city with a population of 386,000. Fortunately, there were no casualties and there was little disruption of life in Christchurch for an earthquake of such a large magnitude. For example, and importantly for our study, all the main maternity facilities in the region remained opened for both birth and postnatal care. Around 90% of the electricity supply in Christchurch was restored by 6pm on the day of the quake.

Because of its inland location, the earthquake did not cause a tsunami but the main shock was followed by almost eighteen months of large, persistent aftershocks (see Figure 1). The most

⁸ <http://www.geonet.org.nz/> (Accessed 06/14/2017)

significant aftershock occurred on February 22, 2011. This had a magnitude of 6.3 and hit very close to the centre of Christchurch resulting in far more damage than the initial earthquake and causing 185 deaths. The aftershocks became much milder in the second half of 2012. Specifically, May 25, 2012 was the last day in our dataset with an earthquake of magnitude 5+ in the region.

Pregnancies in the New Zealand Health System

As noted above, New Zealand has a public health system with free provision of both pre- and post-natal care.

In the Canterbury region during our study period, over 500 women gave birth in a maternity facility each month. By far the largest, and arguably the best equipped, maternity facility in Canterbury is the Christchurch Women's Hospital which sees around 470 births per month (CDHB Data Warehouse: Births at Facility; Accessed 08/07/2014). This hospital remained open for delivery after the earthquake, with little disruption to the services provided. Two Christchurch-based hospitals closed their birthing units temporarily as a result of the February 2011 aftershock: the maternity unit in St. George's Hospital, which normally sees around 30 births per month, remained closed for nearly a year and Burwood Hospital, with around 15 births per month, was closed for five weeks. Women booked into one of these hospitals were given the option of transferring to another facility. Hence, it is unlikely that any negative effects of the earthquake on birth outcomes would operate via reduced access to quality care.

III. Data

Our main data source are all recorded births in New Zealand from 2003 to 2012. We focus on singleton live births with gestation of at least 26 weeks. We further drop a small number of mothers who are missing key variables, such as mother's age or the child's birthweight, or where all their recorded births occurred in the affected area during the seismically active period. This gives us a sample size of 554,598 births. Importantly, we are able to link consecutive births to the same mother in our data. The majority of our analysis focuses on a subsample of mothers with at least two qualifying births during our sample period. This resulting sibling subsample consists of 346,362 births to 150,522 mothers.

New Zealand birth records include standard measures of infant health and we focus on the following: continuous birth weight (BWT), a low birth weight indicator ($BWT < 2,500g$), being

small for gestational-age (BWT<10th percentile for a given gestation), the length of gestation (in weeks), indicators for preterm birth (gestation of 26-36 weeks), being born on time (at 37-42 weeks), and being born postmature (gestation > 42 weeks), the 5-minute Apgar score⁹, a low Apgar score indicator (5-minute Apgar score<7), and whether the child was delivered by a caesarean section. The birth records also collect some basic demographic information for mothers, including their age, ethnicity, prior number of children, residency status, socioeconomic status (measured by the New Zealand Deprivation score of their home address) and the Territorial Local Authority (TLA) of their home address, which we use as control variables in all of our analyses.

Our analyses focus on two time periods. We start by restricting our sibling sample to 271,938 children from 120,741 mothers conceived prior to the first large earthquake on September 4, 2010. By design, there is no selection in pregnancy among these women. We then extend our analysis to consider all pregnancies conceived in our sample period with affected pregnancies defined as those conceived in the areas described above between September 4, 2010 and May 25, 2012 (at the time of data collection, the last day with an earthquake of magnitude 5+). We call this the 'affected period'. While very small earthquakes occur in Canterbury, and the rest of New Zealand, often, the 'affected period' clearly stands out both in terms of the intensity and the number of large quakes (Figures 1 and 2).

Finally, we use data from GeoNet to measure earthquake exposure in each trimester of each pregnancy that occurred in the affected area during the affected period. Specifically, earthquake exposure in the first trimester (E1) is calculated as the total energy released (measured in Joules*10¹⁵) by all recorded earthquakes between the infant's conception date+1 and day 93 of pregnancy. Similarly, earthquake exposure in the second trimester (E2) is calculated as the earthquake intensity between days 94 and 186 of pregnancy and, in the third trimester (E3), between day 187 and birth date-1.¹⁰ All pregnancies outside the affected area and affected time period are coded as having no earthquake exposure even though a very small number of mothers would have experienced earthquakes in other locations at other times while pregnant. This will bias us towards finding less impact of the Canterbury earthquakes as some members

⁹ The Apgar score is an index, ranging from 0 to 10, summarizing the physical condition of a newborn. It is based on a medical practitioner's assessment of the infant's heart rate, respiratory effort, muscle tone, response to stimulation, and skin coloration. As the name suggests, the 5-minute Apgar score measures the newborn's functioning 5 minutes after birth.

¹⁰ As discussed further below, we also consider two alternative measures of earthquake exposure, the occurrence of - or the number of days with - an earthquake of magnitude 5 or above.

of our effective control group are actually treated but given the low prevalence of other large earthquakes during the sample period, this bias should be very small.

Table 1 describes our two main sibling samples and compares them to the full sample of singleton births during the study period. Panel A shows the average outcomes for non-treated women in all three samples. The characteristics of children in the sibling sample are nearly identical to those in the complete sample. This is true as well in the sample restricted to births conceived prior to September 4, 2010. Around 4% of infants have low birth weight, over 5% are born preterm, and around 1% have Apgar scores below 7.

Panels B and C summarise the earthquake experience of pregnant women during our study period. Fewer than 1% of our sampled New Zealand infants experienced major earthquakes (in utero) during any given pregnancy trimester, compared to over 50% of infants in our treatment group. The mean intensity of exposure in the treatment group was over $0.5 \text{ Joule} \cdot 10^{15}$, roughly equivalent to the energy released by a single earthquake of magnitude 6.6.

While over 90% of New Zealand infants in our sample were born to mothers residing in non-affected areas, 5% were born to residents of highly affected areas within greater Christchurch (Panel D).

IV. Main Results

We start by examining the impact of earthquake exposure for children conceived prior to September 4, 2010. Because there is no selection into pregnancy for this group, we can use a simple estimation strategy to examine the impact of earthquake exposure. Specifically, we estimate an OLS model for each birth outcome discussed above including controls for time-varying mother characteristics, child gender and mother fixed effects. Including both time-varying mother characteristics and mother fixed effects allows us to control for the fact that women who gave birth in the area affected by the Canterbury earthquake may differ in both observable and non-observable ways from women who gave birth in other areas of New Zealand and in the same area in other time periods. The regression model can be written as:

$$Y_{ijt} = \alpha_j + \beta_1 E1_{ijt} + \beta_2 E2_{ijt} + \beta_3 E3_{ijt} + \gamma X_{ijt} + \lambda_t + \varepsilon_{ijt} \quad (1)$$

where Y_{ijt} is a birth outcomes for infant i born to mother j at time t , $E1_{ijt}$, $E2_{ijt}$, and $E3_{ijt}$ measure in-utero earthquake exposure in the first, second, and third pregnancy trimester, respectively. The vector of control variables, X_{ijt} , includes the infant's gender and parity, and the mother's

age, ethnicity, NZ residency status, deprivation decile and TLA of her residential address; λ_t are month and year of conception fixed effects and α_j are mother fixed effects.

However, there is one important bias that is left unaddressed by this approach. As has been pointed out by other researchers, stressful events such as earthquakes may cause early delivery which would mechanically lead to less earthquake exposure in the third trimester and a reverse causality in our empirical model (Currie and Rossin-Slater 2013). To address this issue, we follow the previous literature and use an instrumental variables approach to adjust our estimates of the impact of third trimester exposure to stress to account for the impact of stress on gestational length. This approach creates a measure of potential third trimester earthquake exposure that assumes that this trimester lasts exactly 93 days for all births and calculates exposure for this fixed period of time. This measure is then used to instrument for actual exposure. As the instrument takes the same value (zero) as actual exposure for all unaffected pregnancies and similar values for affected pregnancies it is highly correlated with actual exposure.

In Panel A of Table 2, we present the results from this model. We find that earthquake exposure early in a pregnancy reduces the Apgar score. In particular, experiencing an earthquake in the first trimester reduces the 5-minute Apgar score and increases the probability of a score below 7. The probability of a postmature birth is also increased by experiencing earthquakes early in the pregnancy. On the other hand, earthquake exposure later in the pregnancy leads to a shorter gestation. To put our findings in context, the coefficients we report are the effects of increasing the total earthquake energy experienced over the course of a pregnancy trimester by one Joule* 10^{15} . This is equivalent to the energy released by a severe thunderstorm or the energy of an average hurricane released over 2 seconds.¹¹ Experiencing earthquakes of this (cumulative) energy in the first trimester increases the probability of having an Apgar score below 7 by 0.439 percentage points, or 40% of the mean incidence, and the probability of a postmature birth by 0.023 percentage points, or 11%. Experiencing comparable earthquakes in the third trimester has very small effects: it shortens gestation by less than a day, on average.

Because we are estimating a within-mother model, it is not necessary to include non-affected mothers in our estimation. They only help with precision in the sense that their information is also used to estimate the relationship between different covariates and the outcomes of interest.

¹¹ https://en.wikipedia.org/wiki/Orders_of_magnitude_%28energy%29 (Accessed 07/07/17)

In Panel B, we only include women who were pregnant at the time of the first earthquake and estimate the impact of the earthquake by comparing outcomes for the affected child to those previously born to the same mother. While we have less precision, these results are consistent with those estimated using the full sample of births.

Next, we use the best practice methodology for accounting for residential sorting and selection to produce consistent estimates of the impacts of all of the earthquakes that occurred in the Canterbury region between September 4, 2010 and May 25, 2012 on birth outcomes regardless to when the child was conceived. Specifically, we follow Currie and Rossin-Slater (2013) and instrument for each pregnant woman's actual exposure to earthquakes in each trimester of her pregnancy with the exposure she would have experienced based on her residential choice when previously pregnant before the initial earthquake.

We present the results from this estimation in Panel C of Table 2. Our estimates are similar to those in Panels A and B. This is true even though the observable characteristics of these women, specifically their age and prior number of children, differ (see Table 4 which is discussed further below). This suggests that the previous estimates in the literature that use this approach are likely unbiased and that treatment effects are homogenous in the population.

Focusing on exposure to large (magnitude 5+) earthquakes only and ignoring the number and intensity of smaller earthquakes corroborates our findings that experiencing stressful events early in a pregnancy increases the likelihood of a postmature birth while late pregnancy exposure reduces the length of gestation slightly (Table 3). However, when the focus is on major earthquakes only, Apgar scores seem to be negatively affected by late pregnancy exposure rather than early pregnancy exposure as in our other analyses (Panels B and C vs. Panel A).

V. Selection and Heterogenous Treatment Effects

As discussed above, our estimates of the detrimental effects of earthquake-induced stress are similar when we focus on just the impact of the main shock or, in contrast, on all earthquakes controlling for endogenous location decisions using an instrumental variables approach. This could be either because there were no systematic relocations among pregnant women after the initial earthquake or because the instrumental variable technique is accounting for them well. To get an insight into this issue, we compare the observable characteristics of i) affected pregnancies before and after the first earthquake, and ii) people who moved from Canterbury

after a first pregnancy before and after the first earthquake (Table 4). We find that women with affected pregnancies before vs. after the main shock do differ. In particular, mothers in the latter group have more previous children, are more likely to be New Zealand residents or citizens, and slightly more likely to be of Asian ethnicity (Group 2 vs 1 in Table 4). Post-earthquake migrants out of Canterbury are less likely to be European and more likely to be Pacific Islander or Asian but these differences do not reach statistical significance (Group 4 vs 3 in Table 4). Given the different characteristics of women who stayed in Canterbury after the main shock and conceived another child, the fact that our instrumental variable estimates mimic those of the initial shock only suggests that previous studies that use the instrumental variable approach are likely unbiased and that treatment effects are homogenous in the population.

To check that the observed effects on birth outcomes operate via stress in utero rather than any direct impacts of the earthquake, we interact our exposure measures with proxies for the degree of physical damage caused to various neighbourhoods (Table 5). After the Canterbury earthquake, land in Christchurch has been classified into four categories: Green zone technical categories (TC) 1-3 and the red zone (Canterbury Earthquake Recovery Authority, 2011). Land in TC1 is unlikely to incur future earthquake-related damage and standard foundations are generally sufficient. Land in TC2 may incur minor to moderate damage and enhanced foundations may be required. Land in TC3 may suffer moderate to significant damage in large future earthquakes; each site must be reviewed to determine an appropriate foundation design. Land in the red zone poses so high risks for occupants that its residential use has been discontinued after the Canterbury earthquake. All houses in the red zone had to be vacated and will be demolished.

To check whether the effects of the Canterbury earthquake on birth outcomes operate directly via physical damage and a disrupted infrastructure, we interact the trimester exposure measures with indicators for mother's residence in the less affected areas (TC1 and TC2) and the most affected areas (the red zone) – compared to areas with medium damage (TC3). The interaction terms are mostly small and statistically insignificant, strongly suggesting that it is indeed stress that mattered, not the direct impacts of the earthquake.

When we allow the impacts to vary by mother's age (Table 6), we find particularly large impacts of first trimester exposure to earthquakes among teenage mothers (younger than 19

years). This includes reduced birthweight, more pre-term and post-term births and a large sixteen percentage point increase in delivery by caesarean section.

VI. Conclusions

At the time of writing this article, children affected by the Canterbury earthquake in-utero have started school. According to interviews of eight principals from primary schools in Christchurch, these children exhibit behavioural problems and anxiety (demonstrated in un-readiness for school, wetting, nightmares, and aggressive/moody behavior) more than five years after birth (Broughton 2017).

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Figure 1. Earthquakes in the ‘Affected Area’ of Greater Christchurch; Years 2000-2014 (Monthly Number)

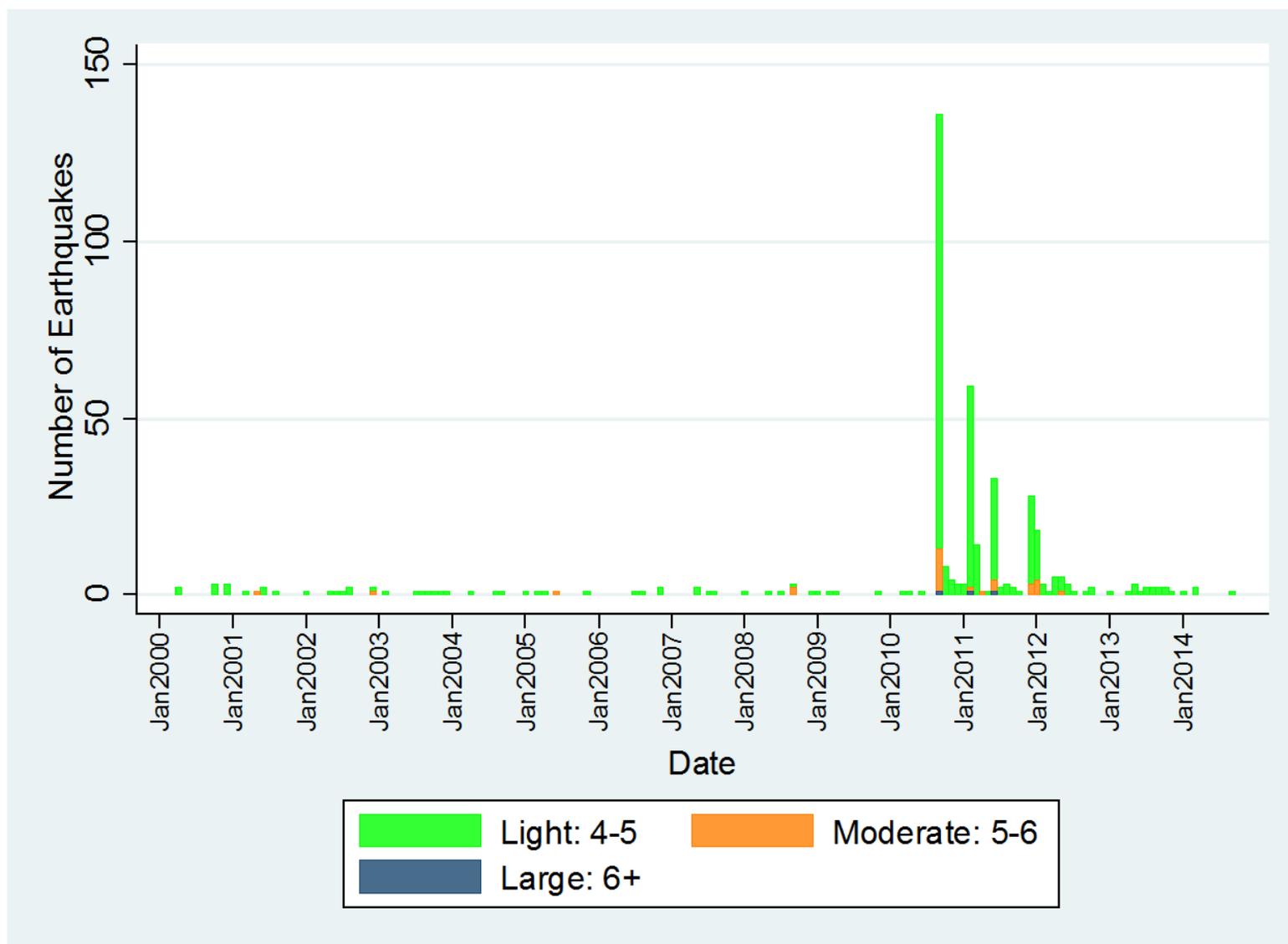
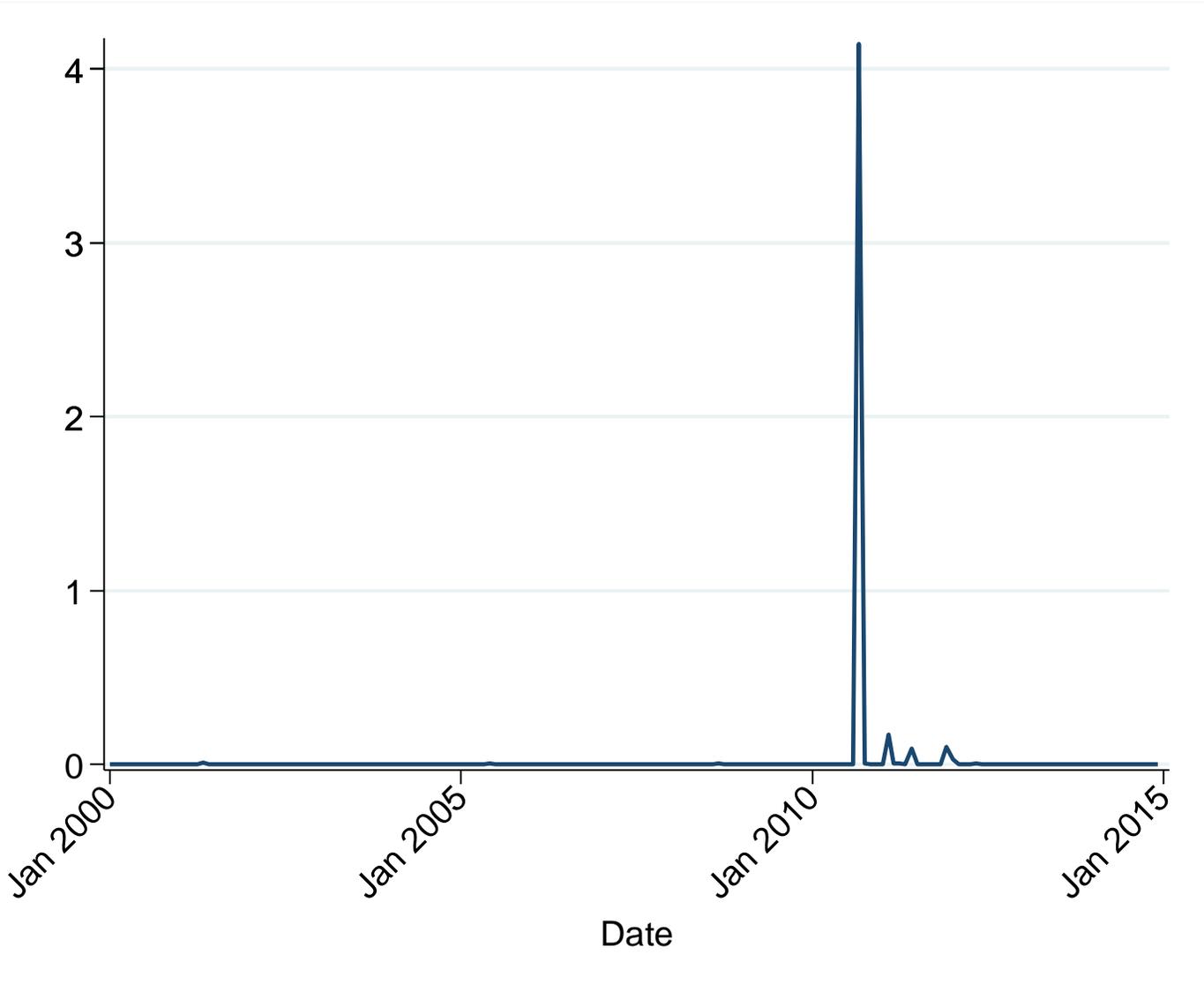
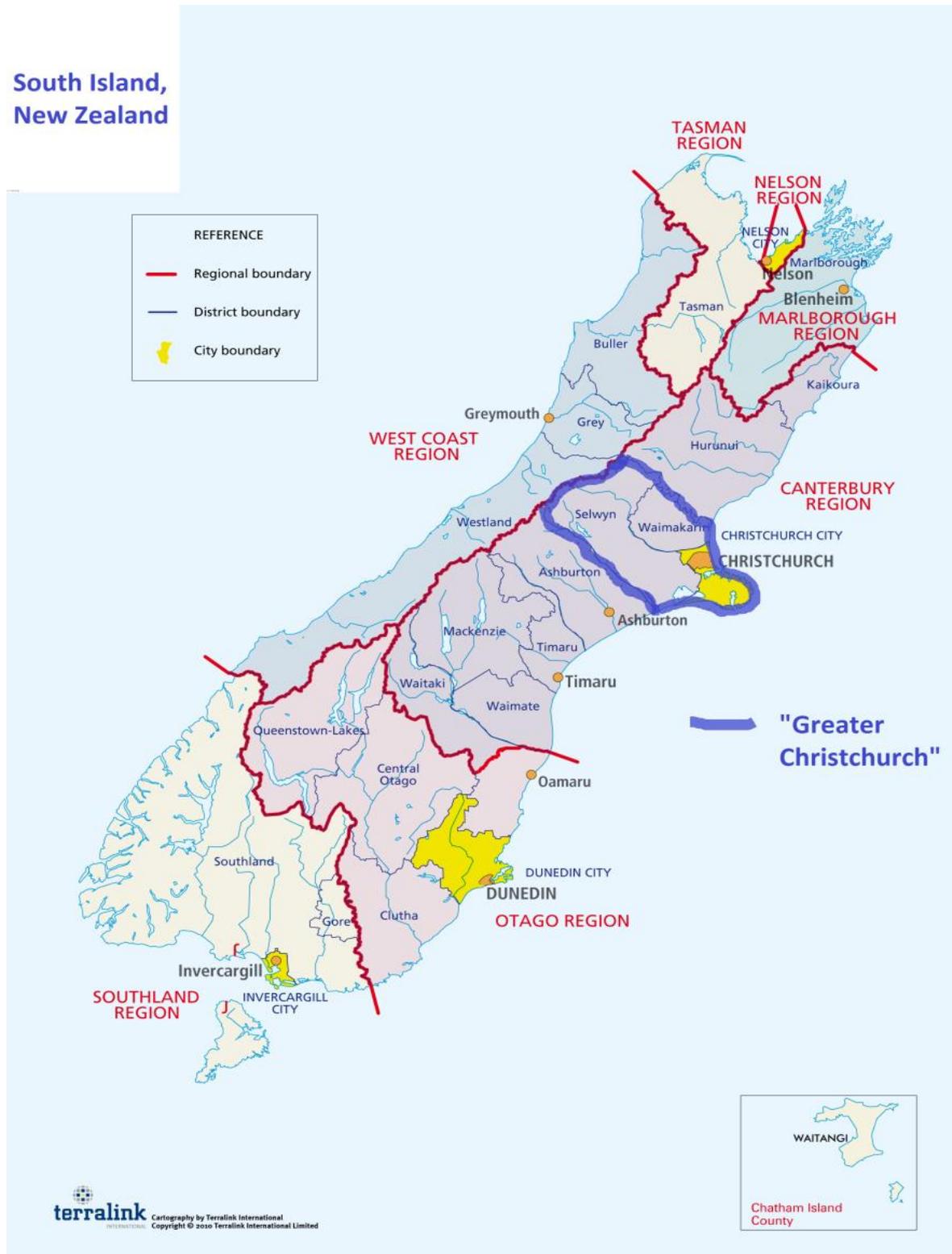


Figure 2. Earthquakes in the 'Affected Area' of Greater Christchurch; Years 2000-2014 (Monthly Energy Released)



Appendix

Figure A1. Map of the South Island of New Zealand with Greater Christchurch as the Earthquake 'Affected Area'



Source: Terralink International (<http://www.lgnz.co.nz/assets/South-Island-PNG.PNG>; Accessed 06/13/2017) with Greater Christchurch added by authors.