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

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ABSTRACT

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

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 trimesters 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.

JEL Classification:	I12, J13, I31
Keywords:	maternal stress, pregnancy, earthquakes, birth weight, Apgar score

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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 heterogenous 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]

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[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 (2018) 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 (2017) look at stress caused by terrorist attacks and other domestic armed conflicts; Carlson (2018; 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) find 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 surprise.[4] 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 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]

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[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.

[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

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 on the same fault line with a magnitude greater than 5, the level where earthquakes are typically strongly felt, including four with a magnitude greater than 6, where some damage is to be expected. 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/epicenter.

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 of 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 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 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

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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.

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 trimesters 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 neighborhood 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, including reduced birthweight, more pre-term and post-term births and a large increase in caesarean sections when exposed to earthquakes in their first trimester. This compounds the fact that teenage mothers already are more likely to experience poor birth outcomes, and likely has serious negative consequences for their offspring.

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 centers in the area.

The main shock of the Canterbury earthquake occurred on September 4, 2010 at 4:35am. The quake had a moment magnitude of 7.1 and was shallow. The epicenter was inland, about 40 kilometers (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.

This first earthquake was followed by almost eighteen months of large, persistent aftershocks (see Figure 1). The most significant aftershock occurred on February 22, 2011. This had a magnitude of 6.3 and hit very close to the center of Christchurch resulting in far more damage than the initial earthquake and causing 185 deaths. The aftershocks finally became much milder in the second half of 2012; the last magnitude 5+ occurred in the region on May 25th until another happened in February 2016.

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[8] http://www.geonet.org.nz/ (Accessed 06/14/2017)

Pregnancies in New Zealand

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 during our entire study period, with little disruption to the services provided. Two Christchurch-based hospitals did close their birthing units temporarily after 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 the earthquakes reduced access to quality hospital care. Home-births are also uncommon in New Zealand with less than 5 percent of births occurring outside the hospital system (NZ Ministry of Health 2017).[9]

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 their first recorded birth 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 multiple 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 score[10], a

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[9] In general, we cannot examine these births because most of our outcome variables are not measured.

[10] 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

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.[11] By design, there is no selection into 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. 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*10^{15}) 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.[12] 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 of our 'control group' are actually treated but given the low prevalence of other large earthquakes during the sample period, this bias should be very small.

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to stimulation, and skin coloration. As the name suggests, the 5-minute Apgar score measures the new-born's functioning 5 minutes after birth. Apgar scores have been found to be predictive of cognitive development, educational and labor force outcomes, as well as early life mortality (Oreopoulos et al. 2008; Figlio et al. 2014).

[11] The date of conception is estimated based on the recorded number of weeks of gestation and the date of birth; this is the standard approach in the literature.

[12] 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.

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 summarize 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 Joule*10^{15}, roughly equivalent to the energy released by a single earthquake of magnitude 6.6 or about 250 earthquakes of magnitude 5.0. 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 unobservable ways from women who gave birth in other areas of New Zealand at the same time and in the same area in other time periods. The regression model can be written as:

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

where Y_{ijt} is a birth outcome 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 Apgar scores. 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 and lower Apgar scores. Women who were pregnant when the first earthquake occurred experienced, on average, 1.32 and 1.30 Joules 10^{-15} of earthquake energy in the first and third trimesters, respectively. Experiencing earthquakes of this (cumulative) energy in the first trimester increases the probability of having an Apgar score below 7 by 0.57 percentage points, or 51% of the mean incidence, and the probability of a postmature birth by 0.03 percentage points, or 15% of the mean incidence. Experiencing comparable earthquakes in the third trimester has very small negative effects on gestation and on Apgar scores.

The impact on Apgar scores found here in the first trimester is likely to have long-run consequences, as previous studies have found them to be predictive of cognitive development, educational and labor force outcomes, as well as early life mortality (Oreopoulos et al. 2008; Figlio et al. 2014). For example, Oreopoulos et al. (2008) finds that compared to infants born with an Apgar score of 10, those with a score below 7 are 32 percentage points more likely to die within one year, have language test scores about one-tenth of a standard deviation lower at

the age of 17, are 4 percentage points less likely to reach grade 12 by age 17, and have a 3 percentage point higher probability of receiving social assistance as a young adult.

Because we are estimating a within-mother model, it is not necessary to include unaffected 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. 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 <u>all</u> 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 ethnicity and immigration status, 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 are more likely to be New Zealand residents or citizens, and 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 only reach statistical significance for Pacific Islanders (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 only the initial shock suggests that previous studies that use the instrumental variable approach are likely unbiased and that treatment effects are homogenous in the population.

Next, we examine whether the effects of the Canterbury earthquake on birth outcomes are likely to have operated directly via physical damage and a disrupted infrastructure, as opposed to via indirect channels, in particular stress. We do this by interacting 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).[13] The results are presented in Table 5. 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.

Finally, we examine whether the impacts of earthquakes vary by mother's age. Teenage and older women both tend to have worse birth outcomes than prime-age women and it seems quite likely that younger women in particular might have a harder time dealing with stress from the earthquakes at the same time as dealing with being pregnant. We find precisely this; allowing the impacts to vary by mother's age (Table 6), We find very large impacts of first trimester

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[13] After the Canterbury earthquake, land in Christchurch has been classified into four categories: Green zone technical categories (TC) 1 to 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. (CERA 2011)

exposure to earthquakes for teenage mothers (younger than 19 years). This includes reduced birthweight, more pre-term and post-term births and increased delivery by caesarean section. For teenage mothers who experienced the average level of earthquake exposure in the first trimester, these coefficients imply that their children were 13% more likely to have a low birthweight, 28% more likely to have a low birth weight for gestational length, 11% more likely to be born early, 12% less likely to be born on time, 1% more likely to be born late and 22% more likely to be delivered via caesarean section relative to the mean incidence among all unaffected mothers. These impacts are likely to have serious negative consequences for the development of these children.

VI.   Conclusions

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. Controlling for observed and unobserved differences between pregnant women in the area affected by the earthquake and other pregnant women, 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 trimesters of pregnancy.

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 behavioral problems and anxiety (demonstrated in un-readiness for school, wetting, nightmares, and aggressive/moody behavior) more than five years after birth (Broughton 2017). These types of developmental problems are consistent with the evidence from other studies that newborn health has important consequences for child development (Figlio et al. 2014). Ideally, future research will be able to follow the children who were in-utero during this highly stressful period for residents of the Canterbury region and examine the consequences for their development and, hopefully, this evidence can be used to design policies that can help mediate these effects for pregnant women in similar situations in the future.

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Figure 1. Earthquakes in the 'Affected Area' of Greater Christchurch; Years 2000-2014 (Monthly Number)
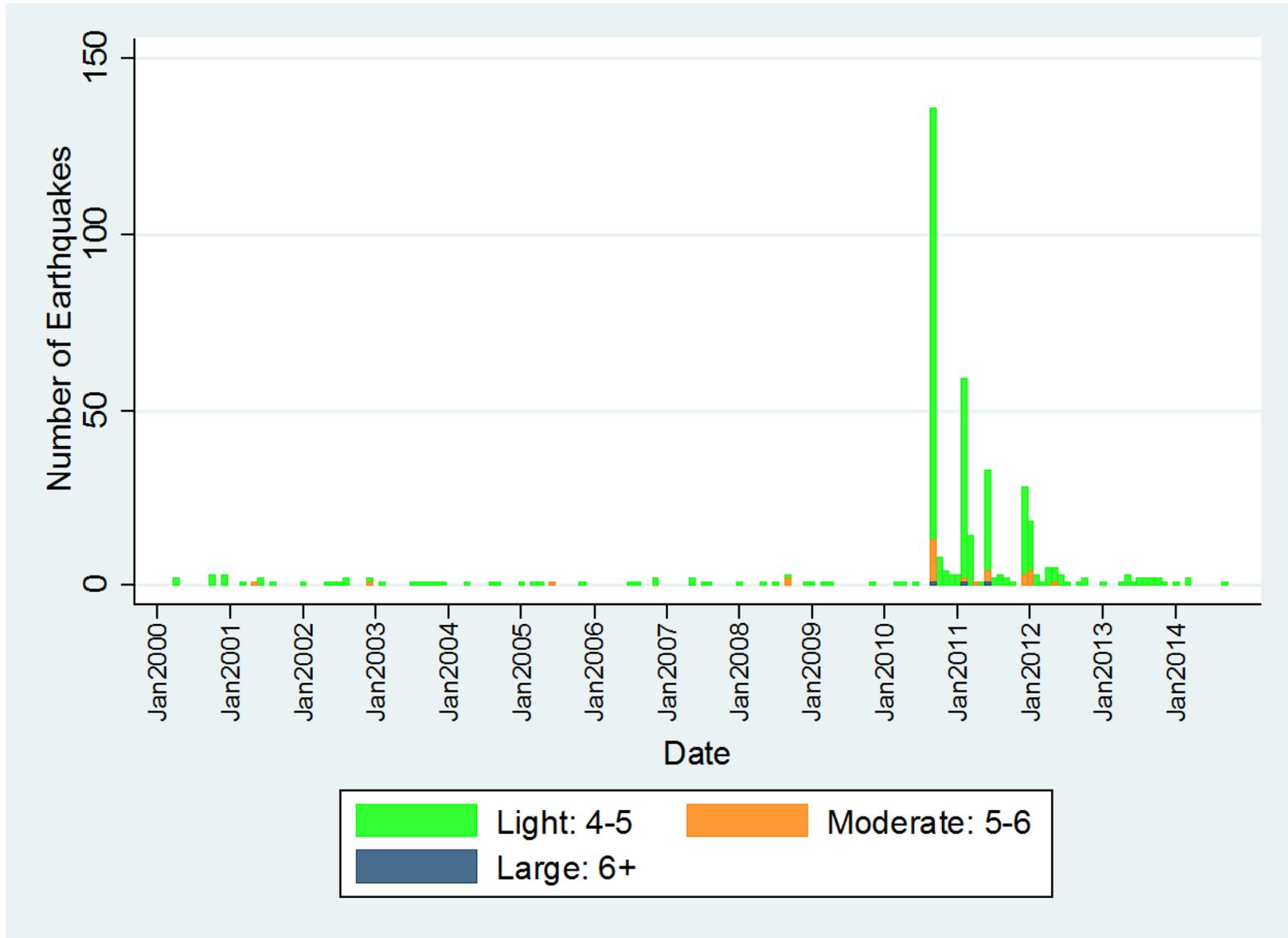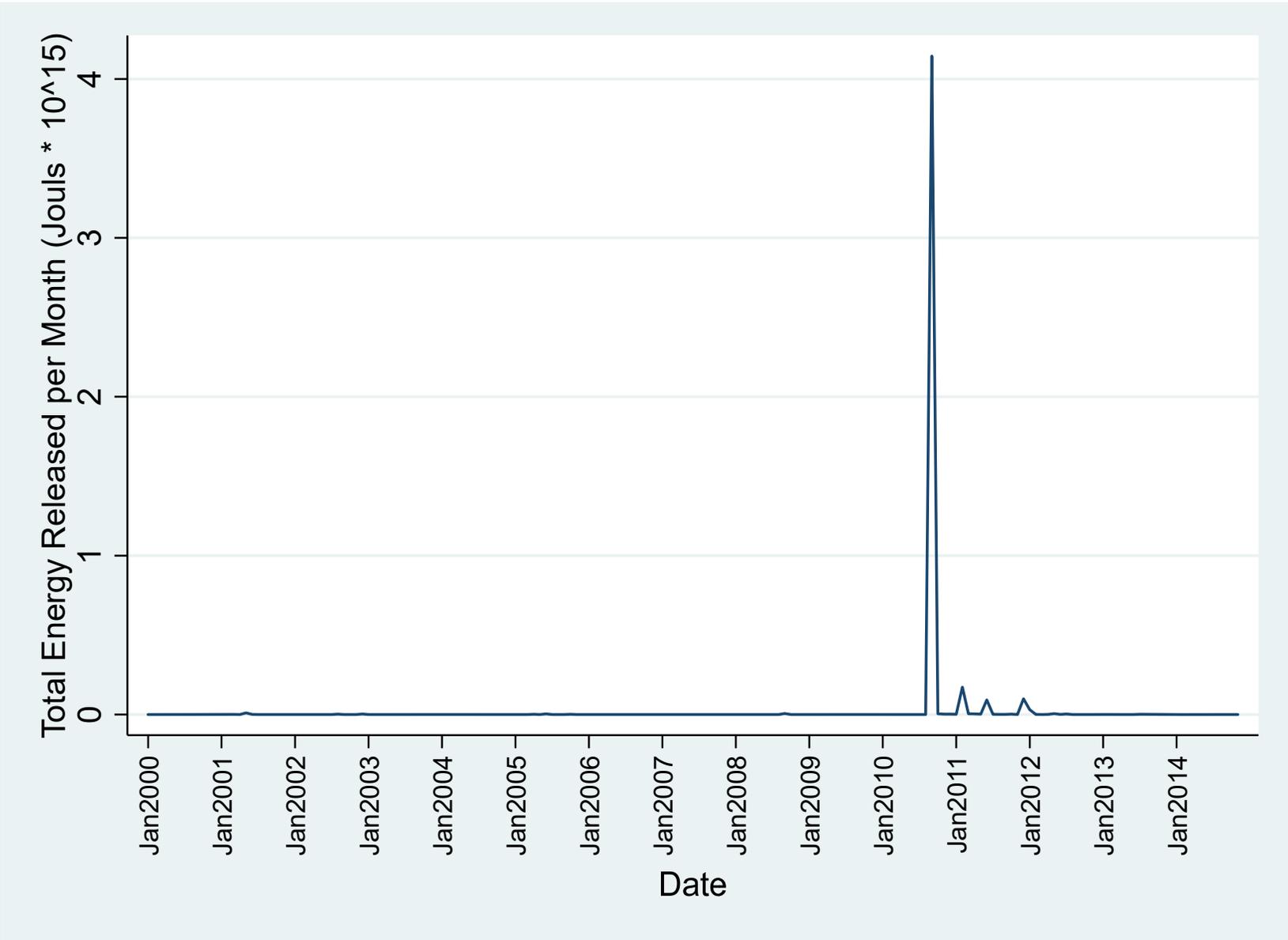
Figure 2. Earthquakes in the 'Affected Area' of Greater Christchurch; Years 2000-2014 (Monthly Energy Released)

Table 1: Summary Statistics

	Full Sample	Sibling Sample	Sibling Sample: Only Pregnancies Before 4/9/10
Panel A: Birth Outcomes - Non-Treated Births Only			
Birth Weight (kg)	3.45	3.48	3.48
Low Birth Weight (<2.5kg)	4.48%	4.04%	3.98%
Birth Weight Low for Gestation	9.91%	9.06%	9.08%
Gestational Age	39.2	39.2	39.2
Preterm (26-36 weeks)	5.73%	5.44%	5.37%
Born on Time (37-42 weeks)	94.1%	94.4%	94.4%
Born Late (>42 weeks)	0.17%	0.18%	0.20%
5 Minute Apgar Score	9.57	9.58	9.59
5 Minute Apgar Score <7	1.23%	1.14%	1.11%
Delivered by C-section	24.2%	22.2%	21.9%
Panel B: Earthquake Exposure - Full Sample			
Total Energy of Quakes in TM1	0.006	0.008	0.009
Total Energy of Quakes in TM2	0.007	0.009	0.011
Total Energy of Quakes in TM3	0.006	0.008	0.009
Any Major Earthquakes in TM 1	0.59%	0.81%	0.23%
Any Major Earthquakes in TM 2	0.66%	0.89%	0.30%
Any Major Earthquakes in TM 3	0.62%	0.84%	0.48%
# Days Major Earthquakes in TM 1	0.014	0.019	0.005
# Days Major Earthquakes in TM 2	0.014	0.019	0.006
# Days Major Earthquakes in TM 3	0.013	0.018	0.010
Panel C: Earthquake Exposure - Treated Birth Only			
Total Energy of Quakes in TM1	0.538	0.541	1.317
Total Energy of Quakes in TM2	0.587	0.595	1.476
Total Energy of Quakes in TM3	0.524	0.517	1.301
Any Major Earthquakes in TM1	52.6%	53.1%	32.1%
Any Major Earthquakes in TM2	58.2%	58.2%	41.4%
Any Major Earthquakes in TM3	55.2%	55.4%	66.0%
# Days Major Earthquakes in TM1	1.22	1.23	0.63
# Days Major Earthquakes in TM2	1.27	1.27	0.81
# Days Major Earthquakes in TM3	1.18	1.19	1.37
Panel D: Timing and Location of Births			
Resident in Red Zone / TC3	4.7%	5.0%	5.2%
Resident in TC1/TC2	2.5%	2.7%	2.8%
Resident in Other Affected Areas	1.1%	1.2%	1.3%
Resident in Non-Affected Areas	91.6%	91.1%	90.7%
Conceived in Treatment Period	23.0%	20.5%	8.1%
Treated Birth	1.1%	1.5%	0.7%
Treated Mother	2.3%	3.4%	2.3%
Number of Births	554,598	346,362	271,938
Number of Mothers	358,758	150,522	120,741

Note: Treated births are all births that were conceived between 29 November 2009 and 25 May 2012 in the Christchurch, Selwyn and Waimakariri Territorial Local Authorities (TLAs) which were the main areas that experienced some earthquake damage. A mother is treated if any of the children she has conceived in the sample period were treated. Total energy is measured in Joules 10^-15.

Table 2: Main Analysis of the Impact of Earthquakes on Child Birth Outcomes

	Birth Weight (kg)	Low Birth Weight (<2.5kg)	Birth Weight Low for Gestation	Gestational Age	Preterm (26-36 weeks)	Born on Time (37-42 weeks)	Born Late (>42 weeks)	5 Minute Apgar Score	5 Minute Apgar Score <7	Delivered by C-section
Panel A: Mother Fixed Effects with Instrumental Variables for Endogenous Length of Pregnancy: Only Pregnancies Conceived Prior to September 4, 2010										
Total Energy of Quakes in TM1	0.00422	-0.00243	-0.00372	0.00314	-0.00366	0.00343	0.000227**	-0.0507***	0.00439**	0.00506
	(0.005)	(0.002)	(0.003)	(0.019)	(0.003)	(0.003)	(0.000)	(0.012)	(0.002)	(0.003)
Total Energy of Quakes in TM2	-0.00216	-0.00193	-0.0023	-0.0313*	0.000698	-0.000879	0.000181*	-0.0099	-0.0014	0.000801
	(0.005)	(0.002)	(0.003)	(0.016)	(0.003)	(0.003)	(0.000)	(0.012)	(0.002)	(0.003)
Total Energy of Quakes in TM3	-0.0056	-0.000437	-0.00291	-0.0366**	0.0041	-0.00425	0.000148	-0.0327**	0.00347	-0.00361
	(0.005)	(0.002)	(0.003)	(0.018)	(0.003)	(0.003)	(0.000)	(0.016)	(0.002)	(0.003)
Number of Births	271,938	271,938	271,938	271,938	271,938	271,938	271,938	193,461	193,461	267,344
Panel B: Mother Fixed Effects with Instrumental Variables for Endogenous Length of Pregnancy: Only Women with Pregnancies Affected by the First Earthquake										
Total Energy of Quakes in TM1	0.0127	-0.00295	-0.011	-0.00968	-0.00644	0.00579	0.000655	-0.021	0.00145	-0.00479
	(0.015)	(0.008)	(0.009)	(0.053)	(0.009)	(0.009)	(0.001)	(0.049)	(0.006)	(0.009)
Total Energy of Quakes in TM2	0.0124	-0.00393	-0.0137	-0.0359	-0.000719	-0.0000381	0.000757	0.00955	-0.007	-0.0087
	(0.015)	(0.008)	(0.009)	(0.053)	(0.009)	(0.009)	(0.001)	(0.051)	(0.007)	(0.009)
Total Energy of Quakes in TM3	0.00589	-0.000945	-0.0169**	-0.0645	0.000822	-0.000874	0.0000526	-0.000814	-0.00451	-0.0140*
	(0.013)	(0.007)	(0.008)	(0.046)	(0.007)	(0.007)	(0.000)	(0.041)	(0.005)	(0.008)
Number of Births	6,295	6,295	6,295	6,295	6,295	6,295	6,295	5,307	5,307	6,252
Panel C: Mother Fixed Effects with Instrumental Variables for Endogenous Location and Length of Pregnancy: All Pregnancies										
Total Energy of Quakes in TM1	0.00885	-0.00185	-0.00617*	0.00914	-0.00417	0.00387	0.000299***	-0.0555***	0.00430**	0.00601*
	(0.006)	(0.003)	(0.004)	(0.021)	(0.003)	(0.003)	(0.000)	(0.014)	(0.002)	(0.004)
Total Energy of Quakes in TM2	-0.00144	-0.00103	-0.00251	-0.0424**	0.000945	-0.00117	0.000222**	-0.0045	-0.00264	0.00141
	(0.005)	(0.002)	(0.003)	(0.017)	(0.003)	(0.003)	(0.000)	(0.013)	(0.002)	(0.003)
Total Energy of Quakes in TM3	-0.0103*	-0.000106	-0.00162	-0.0530***	0.00466	-0.00466	0.00000463	-0.0226	0.00322	-0.0021
	(0.005)	(0.002)	(0.004)	(0.019)	(0.003)	(0.003)	(0.000)	(0.017)	(0.002)	(0.003)
Number of Births	346,362	346,362	346,362	346,362	346,362	346,362	346,362	249,226	249,226	340,888

Note: * p<0.10, ** p<0.05, *** p<0.01. Standard errors, in parentheses, are clustered by mother. Each regression also controls for each child's gender and birth parity, each mother's age, ethnicity, residency status, socioeconomic status (measured by NZDep of their home address) and location (TLA), and month and year of conception. Total energy is measured in Joules 10^-15. In Panel A and B, the variable measuring exposure to earthquakes in trimester 3 is instrumented for with a similar variable calculated under the assumption of a full term birth, In Panel C, the variables measuring exposure to earthquakes are instrumented for with similar variables calculated under the assumption of a full term birth and that the residential location is the same as the most recent previous birth of the same mother.

Table 3: Does the Measurement of Earthquake Exposure Matter? (All Mother FEs with Instruments)

	Birth Weight (kg)	Low Birth Weight (<2.5kg)	Birth Weight Low for Gestation	Gestational Age	Preterm (26-36 weeks)	Born on Time (37-42 weeks)	Born Late (>42 weeks)	5 Minute Apgar Score	5 Minute Apgar Score <7	Delivered by C-section
				Panel A: Total Energy of Earthquakes in each Trimester						
Total Energy of Quakes in TM1	0.00885	-0.00185	-0.00617*	0.00914	-0.00417	0.00387	0.000299***	-0.0555***	0.00430**	0.00601*
	(0.006)	(0.003)	(0.004)	(0.021)	(0.003)	(0.003)	(0.000)	(0.014)	(0.002)	(0.004)
Total Energy of Quakes in TM2	-0.00144	-0.00103	-0.00251	-0.0424**	0.000945	-0.00117	0.000222**	-0.0045	-0.00264	0.00141
	(0.005)	(0.002)	(0.003)	(0.017)	(0.003)	(0.003)	(0.000)	(0.013)	(0.002)	(0.003)
Total Energy of Quakes in TM3	-0.0103*	-0.000106	-0.00162	-0.0530***	0.00466	-0.00466	0.00000463	-0.0226	0.00322	-0.0021
	(0.005)	(0.002)	(0.004)	(0.019)	(0.003)	(0.003)	(0.000)	(0.017)	(0.002)	(0.003)
				Panel B: Experienced Any Major (5+) Earthquakes in each Trimester						
Any Major Earthquakes in TM1	-0.00261	0.00507	-0.00182	0.00792	0.00817	-0.00873	0.000567**	-0.0371	0.00438	0.0217**
	(0.016)	(0.008)	(0.009)	(0.056)	(0.009)	(0.009)	(0.000)	(0.036)	(0.005)	(0.009)
Any Major Earthquakes in TM2	-0.00124	0.00208	0.00166	-0.0942**	0.00486	-0.00581	0.000959***	-0.00812	-0.00365	0.00222
	(0.012)	(0.006)	(0.007)	(0.043)	(0.007)	(0.007)	(0.000)	(0.030)	(0.004)	(0.007)
Any Major Earthquakes in TM3	-0.0253*	-0.00158	0.00171	-0.0548	-0.00783	0.00751	0.000319	-0.0812**	0.00704	-0.00781
	(0.015)	(0.007)	(0.009)	(0.053)	(0.008)	(0.008)	(0.000)	(0.037)	(0.005)	(0.009)
				Panel C: Number of Days Experiencing Any Major (5+) Earthquakes in each Trimester						
# Days Major Quakes in TM1	-0.00124	-0.000491	-0.000232	0.0166	0.00228	-0.00251	0.000237**	-0.0127	0.00132	0.00489
	(0.006)	(0.003)	(0.004)	(0.021)	(0.003)	(0.003)	(0.000)	(0.014)	(0.002)	(0.004)
# Days Major Quakes in TM2	-0.0013	0.00228	0.00138	-0.0412**	0.00135	-0.00175	0.000396***	-0.0094	-0.0000455	0.00176
	(0.005)	(0.002)	(0.003)	(0.019)	(0.003)	(0.003)	(0.000)	(0.013)	(0.002)	(0.003)
# Days Major Quakes in TM1	-0.0115*	0.00135	-0.000177	-0.0459**	-0.00118	0.00103	0.000151	-0.0309**	0.00232	0.00103
	(0.006)	(0.003)	(0.004)	(0.021)	(0.003)	(0.003)	(0.000)	(0.015)	(0.002)	(0.004)
Number of Births	346,362	346,362	346,362	346,362	346,362	346,362	346,362	249,226	249,226	340,888

Note: * p<0.10, ** p<0.05, *** p<0.01. Standard errors, in parentheses, are clustered by mother. Each regression also controls for each child's gender and birth parity, each mother's age, ethnicity, residency status, socioeconomic status (measured by NZDep of their home address) and location (TLA), and month and year of conception. Total energy is measured in Joules 10^{-15}. In each panel, the variables measuring exposure to earthquakes are instrumented for with similar variables calculated under the assumption of a full term birth and that the residential location is the same as the both recent previous birth of the same mother.

Table 4: Who Has Children When Earthquakes Are Happenning? (Summary Statistics and T-Tests)

	Group 1	Group 2	Group 3	Group 4	Group 2 vs 1	Group 4 vs 3
	Affected Pregnancies Before 4/9/10	Affected Pregnancies After 4/9/10	Movers with Pregnancies Before 4/9/10	Movers with Pregnancies After 4/9/10	Difference, Standard Error and Significance	Difference, Standard Error and Significance
Mother's Age	29.9	29.8	30.3	29.8	-0.106	-0.412
	(5.94)	(5.87)	(5.29)	(5.69)	(0.111)	(0.408)
Mother Has No Previous Children	42.7%	43.5%	N/A	N/A	0.008	0.000
	(0.49)	(0.50)			(0.010)	(0.000)
Mother Has One Previous Child	35.5%	35.7%	47.1%	50.7%	0.002	0.036
	(0.48)	(0.48)	(0.50)	(0.50)	(0.010)	(0.039)
Mother Has Two Previous Children	13.8%	13.7%	32.8%	30.3%	-0.001	-0.025
	(0.35)	(0.34)	(0.47)	(0.46)	(0.007)	(0.036)
Mother Has Three or More Previous Kids	8.0%	7.1%	20.1%	19.0%	-0.008	-0.011
	(0.27)	(0.26)	(0.40)	(0.39)	(0.005)	(0.030)
Mother is a NZ Resident/Citizen	91.3%	93.3%	95.5%	94.6%	0.0201***	-0.009
	(0.28)	(0.25)	(0.21)	(0.23)	(0.005)	(0.016)
Mother is European Ethnicity	70.4%	70.2%	65.6%	60.6%	-0.002	-0.049
	(0.46)	(0.46)	(0.48)	(0.49)	(0.009)	(0.036)
Mother is Maori Ethnicity	12.3%	11.5%	23.0%	23.1%	-0.008	0.002
	(0.33)	(0.32)	(0.42)	(0.42)	(0.006)	(0.032)
Mother is Pacific Island Ethnicity	4.1%	4.3%	4.5%	7.6%	0.002	0.0307*
	(0.20)	(0.20)	(0.21)	(0.26)	(0.004)	(0.017)
Mother is Asian Ethnicity	10.6%	11.9%	4.5%	6.7%	0.0126**	0.022
	(0.31)	(0.32)	(0.21)	(0.25)	(0.006)	(0.016)
Mother is Other Ethnicity	2.4%	2.0%	2.5%	2.0%	-0.004	-0.005
	(0.15)	(0.14)	(0.16)	(0.14)	(0.003)	(0.011)
NZ Deprivation Index of Home Address	5.25	5.21	5.48	5.56	-0.036	0.080
	(2.66)	(2.67)	(2.72)	(2.70)	(0.050)	(0.205)
Number of Births	4,138	7,539	244	554		

Notes: The first four columns present means and standard deviations, in parentheses, of different characteristics of three groups of mothers. The last two columns present the results of separate regressions for each variable testing whether the means are different between each of the groups. * p<0.10, ** p<0.05, *** p<0.01. Standard errors, in parentheses, are clustered by mother.

Table 5: Do Impacts Vary by the Amount of Local Physical Damage? (Mother FEs with Instruments)

	Birth Weight (kg)	Low Birth Weight (<2.5kg)	Birth Weight Low for Gestation	Gestational Age	Preterm (26-36 weeks)	Born on Time (37-42 weeks)	Born Late (>42 weeks)	5 Minute Apgar Score	5 Minute Apgar Score <7	Delivered by C-section
				Main Effects - Less Effected Areas						
Total Energy of Quakes in TM1	0.0337	-0.00659	-0.00859	0.139**	-0.0121	0.0119	0.000225	-0.0939	0.00632	-0.00201
	(0.022)	(0.009)	(0.013)	(0.066)	(0.008)	(0.008)	(0.000)	(0.064)	(0.009)	(0.013)
Total Energy of Quakes in TM2	0.0151	0.00148	0.00146	-0.0263	0.00171	-0.00179	0.000083	-0.0579	0.001	0.00519
	(0.020)	(0.006)	(0.012)	(0.066)	(0.010)	(0.010)	(0.000)	(0.046)	(0.006)	(0.012)
Total Energy of Quakes in TM3	-0.0149	-0.0111	0.00286	-0.057	0.00665	-0.00471	-0.00195	0.0536	0.000572	0.00461
	(0.022)	(0.009)	(0.011)	(0.083)	(0.011)	(0.011)	(0.002)	(0.078)	(0.012)	(0.014)
				Interactions for Medium Effected Areas						
Total Energy of Quakes in TM1	-0.035	0.00437	0.000842	-0.166**	0.00805	-0.00813	0.0000845	0.0513	-0.000541	0.015
	(0.025)	(0.011)	(0.014)	(0.074)	(0.009)	(0.009)	(0.000)	(0.066)	(0.009)	(0.014)
Total Energy of Quakes in TM2	-0.0199	-0.00295	0.00148	-0.0623	0.0014	-0.00157	0.000175	0.0665	-0.00569	-0.0055
	(0.022)	(0.007)	(0.014)	(0.071)	(0.011)	(0.011)	(0.000)	(0.049)	(0.007)	(0.013)
Total Energy of Quakes in TM3	0.00298	0.0107	-0.00882	0.00837	-0.00531	0.00307	0.00224	-0.0971	0.00324	-0.0102
	(0.024)	(0.011)	(0.013)	(0.091)	(0.013)	(0.013)	(0.002)	(0.085)	(0.013)	(0.015)
				Interactions for Most Effected Areas						
Total Energy of Quakes in TM1	-0.0249	0.00619	0.00407	-0.140**	0.00989	-0.00997	0.0000851	0.0397	-0.00345	0.00568
	(0.023)	(0.010)	(0.014)	(0.071)	(0.009)	(0.009)	(0.000)	(0.066)	(0.009)	(0.014)
Total Energy of Quakes in TM2	-0.0181	-0.00281	-0.00728	0.00264	-0.00193	0.00179	0.000146	0.0561	-0.00325	-0.00368
	(0.021)	(0.007)	(0.013)	(0.069)	(0.010)	(0.010)	(0.000)	(0.049)	(0.007)	(0.013)
Total Energy of Quakes in TM3	0.00646	0.0134	-0.00342	0.00311	-0.000893	-0.00133	0.00223	-0.079	0.00282	-0.00653
	(0.023)	(0.010)	(0.012)	(0.085)	(0.012)	(0.012)	(0.002)	(0.080)	(0.012)	(0.015)
Number of Births	346,362	346,362	346,362	346,362	346,362	346,362	346,362	249,226	249,226	340,888

Note: * p<0.10, ** p<0.05, *** p<0.01. Standard errors, in parentheses, are clustered by mother. Each regression also controls for each child's gender and birth parity, each mother's age, ethnicity, residency status, socioeconomic status (measured by NZDep of their home address) and location (TLA and effected zone), and month and year of conception. Total energy is measured in Joules 10^{-15}. The variables measuring exposure to earthquakes and their interactions are instrumented for with similar variables calculated under the assumption of a full term birth and that the residential location is the same as the both recent previous birth of the same mother.

Table 6: Do Impacts Vary by Mother's Age? (Mother FEs with Instruments)

	Birth Weight (kg)	Low Birth Weight (<2.5kg)	Birth Weight Low for Gestation	Gestational Age	Preterm (26-36 weeks)	Born on Time (37-42 weeks)	Born Late (>42 weeks)	5 Minute Apgar Score	5 Minute Apgar Score <7	Delivered by C-section
				Main Effects - Mothers Aged 19-39						
Total Energy of Quakes in TM1	0.00897	-0.00158	-0.00567	0.0148	-0.00398	0.00368	0.000301***	-0.0561***	0.00441**	0.00714**
	(0.006)	(0.003)	(0.004)	(0.022)	(0.003)	(0.003)	(0.000)	(0.014)	(0.002)	(0.004)
Total Energy of Quakes in TM2	0.000942	-0.000957	-0.00262	-0.0350**	0.000444	-0.000662	0.000217**	-0.00755	-0.00249	0.0022
	(0.005)	(0.002)	(0.003)	(0.018)	(0.003)	(0.003)	(0.000)	(0.013)	(0.002)	(0.003)
Total Energy of Quakes in TM3	-0.00990*	-0.000414	0.000188	-0.0475**	0.00412	-0.0041	-0.0000128	-0.0212	0.00271	-0.00209
	(0.006)	(0.003)	(0.004)	(0.020)	(0.003)	(0.003)	(0.000)	(0.017)	(0.003)	(0.003)
				Interactions for Younger Mothers (<19)						
Total Energy of Quakes in TM1	-1.369	0.0976***	0.221***	0.644	0.0882*	-0.0959*	0.00769**	-1.084	0.148	0.163***
	(0.988)	(0.019)	(0.063)	(2.419)	(0.054)	(0.054)	(0.003)	(2.498)	(0.115)	(0.044)
Total Energy of Quakes in TM2	-0.0906***	0.00373	0.00588	-0.0276	-0.0708*	0.0708*	0.0000352	0.311	-0.0613	-0.0626
	(0.030)	(0.003)	(0.008)	(0.062)	(0.041)	(0.041)	(0.000)	(0.213)	(0.043)	(0.042)
Total Energy of Quakes in TM3	0.0165	-0.0416	-0.0617	-0.00978	0.0206	-0.0208	0.000184	0.048	0.00111	-0.0785
	(0.067)	(0.035)	(0.056)	(0.233)	(0.080)	(0.080)	(0.000)	(0.132)	(0.004)	(0.068)
				Interactions for Older Mothers (>39)						
Total Energy of Quakes in TM1	-0.00275	-0.00747	-0.0142	-0.154**	-0.00489	0.00494	-0.0000504	0.0171	-0.00298	-0.0308**
	(0.021)	(0.011)	(0.017)	(0.078)	(0.011)	(0.011)	(0.000)	(0.070)	(0.002)	(0.014)
Total Energy of Quakes in TM2	-0.0534*	-0.00217	0.00238	-0.186*	0.0189	-0.019	0.000119	0.0565	0.00298	-0.0142
	(0.029)	(0.010)	(0.016)	(0.106)	(0.016)	(0.016)	(0.000)	(0.049)	(0.002)	(0.016)
Total Energy of Quakes in TM3	-0.0100	0.0116	-0.0295	-0.1100	0.00854	-0.00887	0.000335	-0.0392	0.0115	0.00981
	(0.024)	(0.011)	(0.020)	(0.070)	(0.015)	(0.015)	(0.000)	(0.087)	(0.014)	(0.019)
Number of Births	346,362	346,362	346,362	346,362	346,362	346,362	346,362	249,226	249,226	340,888

Note: * $p<0.10$, ** $p<0.05$, *** $p<0.01$. Standard errors, in parentheses, are clustered by mother. Each regression also controls for each child's gender and birth parity, each mother's age, ethnicity, residency status, socioeconomic status (measured by NZDep of their home address) and location (TLA), and month and year of conception. Total energy is measured in Joules 10^{-15}. The variables measuring exposure to earthquakes and their interactions are instrumented for with similar variables calculated under the assumption of a full term birth and that the residential location is the same as the both recent previous birth of the same mother.

Appendix

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