The Relationship Between Prenatal Stress Due to Natural Disasters and the Long-Term Educational Achievement of Chilean Students

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Abstract

This study investigated the effect of prenatal exposure to stress from a natural disaster on long-term educational outcomes in the offspring of such pregnancies. The study hypothesized that offspring of mothers that experience an earthquake during their pregnancy would have poorer academic achievement in high school and college.

Previous research has linked prenatal stress to lower birth weight and lower gestational age at delivery (Norbeck & Tilden, 1983; Rondó et al., 2003; Sable & Wilkinson, 2000; Torche, 2011a) and prenatal stress caused by natural disasters has been related to lower educational outcomes and cognitive development (Charil et al., 2010; Fuller, 2014). However, these educational outcome investigations tend to have two weaknesses. The first group of research papers analyzes very small samples (Charil et al., 2010; King & Laplante, 2005; Weinstock, 2005), making it difficult to generalize results. Large population survey research using standardized test scores follows students for shorter periods of time (Fuller, 2014). Consequently, the test score results may have a low impact on students' lives as small changes in these scores may have little educational or practical relevance. To ameliorate these weaknesses, this thesis uses larger sample sizes, following students over a longer period of time measuring consequential educational outcomes such as educational tests scores, high school GPAs and college graduation rates.

This study follows a cohort of Chilean students affected prenatally by the 1985 earthquake in central Chile and tracks their educational performance using three different measures: their performance on the national standardized Tests of the System of Quality Measurement in Education (SIMCE), the students' high school GPAs, and their college graduation rates by age 32. These three measures investigate learning outcomes measured as the standardized tests scores and GPAs, and specifically focus on the effects of high school performance and the likelihood of college graduation, which is presumed to have long-lasting effects on earning ability and quality of life.

Students prenatally exposed to the earthquake were compared with students who were not affected by the earthquake. The results show that prenatally affected students had lower performance in some of the measured variables, with lower income students having the worst outcomes. This research generates evidence of long-term negative effects associated with prenatal stress.

Dedication

I dedicate this thesis to my husband, Francisco Meneses, and to everyone who ever had to overcome pregnancy difficulties

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I would like to thank Dr. Dante Spetter and my husband Francisco Meneses for their support in this journey.

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Chapter I

Introduction

Does prenatal exposure to stress from a natural disaster affect long-term educational outcomes in the offspring of such pregnancies? Natural disasters have adverse effects on affected populations resulting in enormous economic and psychosocial costs (Debarati et al., 2013). However, there is limited scientific data on the possible effects for pregnant women and their offspring beyond the known increased risk of preterm labor and premature delivery (Norbeck & Tilden, 1983; Rondó et al., 2003; Sable & Wilkinson, 2000; Torche, 2011a).

Recent research on acute prenatal stress outcomes indicates that there could be long-lasting consequences on fetal development when a pregnant woman experiences very high levels of stress (Fuller, 2014). The literature has shown that women who are exposed to acute stressors early in their pregnancy have a higher risk of preterm labor and premature delivery that can significantly impact psychological and intellectual development of the child (Charil et al., 2010; King & Laplante, 2005; Weinstock, 2005). However, it is unknown whether or to what degree this may affect long-term cognitive development and educational outcomes of infants whose mothers were exposed to high levels of stress during pregnancy.

Hypothesis

The hypothesis of this research was that when a mother survives an earthquake during her pregnancy, her offspring will have poorer academic achievement. This investigation tested the hypothesis using standardized high school test scores, academic grades, and college graduation status of the exposed population versus their peers whose mothers were not exposed to an earthquake during pregnancy.

Children born in the aftermath of a major earthquake in the central regions of Chile in 1985 were assessed based on national data bases, comparing those in the earthquake region and those whose mothers were in regions not affected by the earthquake.

The research relied on national datasets to infer the effects of this natural disaster and to compare the outcomes of teenagers who were presumed to be affected in utero (based on geographic proximity to the epicenter) versus those who were not. To date, no studies have specifically evaluated the long-term (18+ years) consequences of prenatal stress due to a natural disaster on educational outcomes in the offspring of such pregnancies or if these effects are higher for lower-income individuals. This study provides a better understanding of the effects of maternal stress exposure and its impact on long-term educational achievement.

Background of the Problem

The relationship between maternal stress and birth outcomes has been studied for more than five decades (Graignic-Philippe et al., 2014). A critical review of the literature (Graignic-Philippe et al., 2014) showed that prenatal stress was significantly related to impairment in child behavioral and cognitive development. Much of this research was conducted using large population samples exposed to natural disasters, in an attempt to isolate the effects of the event from the effects of confounding variables such as social economic status (SES), substance abuse, unemployment, etc.

There are two lines of research regarding prenatal stress caused by natural disasters. The first line analyzes the impact of natural disasters using small, post-disaster samples (e.g., Dancause et al., 2011; Dirkzwager et al., 2006; King & Laplante, 2005; Norris et al., 2002; Yzermans et al., 2005). Because it is impossible to anticipate natural disasters, it is difficult to prepare in advance for such research, and most outcome studies lack baseline data. When there is pre-disaster data available for a particular cohort, follow-up data is typically available for only a subset of the initial sample as the loss of utilities, housing, and employment leads to increased relocation (Canino et al., 1990; Fernandez et al., 2017).

Other research on disasters relies on national census, governmental records, or cohort data to analyze national or regional groups of affected populations. These studies usually do not use psychometric assessment of individual functioning, but rather infer the negative outcomes using epidemiological, demographic, educational, or labor datasets (Currie & Rossin-Slater, 2013; Fuller, 2014; Simeonova, 2011; Torche, 2011a). The results of both types of studies rely on two assumptions. First, disasters are an exogenous shock; thus, they are random and not correlated with any other factor. The second assumption is that these natural disasters are bounded by geography, time, or other measurable factors. These factors are exploited by researchers to identify exposed and unexposed groups of the population to measure the impact of these natural disasters. The use of national studies and large datasets allows researchers to identify relatively small effects by comparing people in the locale of the disaster to people further from the event.

The earliest studies of maternal exposure to stress focused on pregnancy outcomes, specifically the association between stress exposure and birth weight and gestational age at birth. These studies showed that increased maternal stress predicted lower birth weight (<2500 g) and shorter gestational time (<37 weeks) (Norbeck & Tilden, 1983; Rondó et al., 2003; Sable & Wilkinson, 2000; Torche, 2011a). These authors assessed maternal psychological distress through surveys and case-control studies evaluating women before and after the 16th week of pregnancy and in some cases followed the child after pregnancy (samples ranging from 117 to 865 pregnant women).

It has been suggested that the younger gestational age at time of delivery and consequent lower birth weight could be due to increases in maternal stress hormones (Dirkzwager et al., 2006; Gutteling et al., 2006; Hobel & Culhane, 2003; Weinstock, 2005). Studies have linked maternal stress and increased stress hormone levels during pregnancy not only to lower birth weight and preterm delivery, but also to lower mathematics and reading test scores for 4- to 6-year-old offspring. In addition, cognitive, behavioral, and emotional complications are reportedly more prevalent in affected offspring versus nonaffected control groups (Boardman et al., 2002; King & Laplante, 2005; Torche, 2011a).

For example, high stress and anxiety levels in pregnant women increase the risk of spontaneous abortion (miscarriage) and preterm birth (Mulder et al., 2002). Higher maternal stress is also associated with lower birth weight and higher incidence of birth defects in full-term babies. There are several possible mechanisms relating stress to fetal development. One of these mechanisms is through the effects of cortisol, a stress hormone that is generally elevated when people confront stressful life events, such as natural disasters. Elevated maternal cortisol is associated with negative birth outcomes such as preterm delivery (Charil et al., 2010; Wadhwa et al., 2004).

Prenatal stress has been divided into two main classifications: a) chronic stress, a long-term experience which is often related to life experiences such as the loss of a family member or employment difficulties and b) acute stress, which is of a shorter duration. Natural disasters, accidents, death of a spouse, and divorce are included in this acute category, even though for all of these events there may be longer-term stress impacting the individuals over several months (Huizink et al., 2004; Schneiderman et al., 2005).

Focusing on acute stress or one-time events, the effect of prenatal stress on child development has been evaluated using post-disaster maternal surveys. Glynn et al. (2001) studied a group of 281 mothers who experienced an earthquake in California. The authors rated maternal stress using a 4-point Likert-type scale, ranging from not at all stressed to extremely stressed. They found that their measurement of stress related to the earthquake was associated with children being delivered at a lower gestational age. While children whose mothers were exposed during their first trimester to the earthquake had an average gestational age of 38.06 weeks at birth, non-exposed children averaged a gestational age of 39.5 weeks. More recently, Tan et al. (2009) evaluated birth outcomes after a catastrophic 8.0 earthquake in Wenchuan, China. They used a hospital-based dataset to compare the ratio of congenital disabilities and infants' birth weight in pre- and post-earthquake groups, analyzing a sample of 6,638 pre- and 6,365 post-earthquake neonates.

The affected and control groups were born up to one year after and up to one year before the earthquake, respectively. They reported an increased incidence of low birthweight and preterm delivery for neonates affected during the first trimester of pregnancy. The proportion of children classified as low birthweight was 5.01% in the post-earthquake period versus 3.72% in the pre-earthquake period. Also, there were more preterm births reported following the earthquake (7.41%) compared to the period preceding the earthquake (5.63%, $p<0.01$). Exposed mothers' babies had more birth defects, including cleft lip/palate, polydactylia, and microtia (a congenital deformity where the external ear is underdeveloped), among other defects. The overall ratio of birth defects in the post-earthquake group was higher (1.18%), and statistically significant when compared with the pre-earthquake group ratio of birth defects (0.99%).

King and Laplante (2005) followed a small group of students for six years. These authors followed 150 children who were exposed in utero to a natural disaster. The researchers measured prenatal exposure to a severe storm and maternal stress levels caused by massive storms in Canada in 1998. The authors used the Bayley Mental Development Index (MDI) scores to measure the children's intellectual ability and the MacArthur Communicative Development Index (MCDI) to evaluate verbal comprehension and word usage. After controlling for maternal education and socioeconomic status as well as other demographic variables, the researchers found that maternal stress level during the prenatal period was inversely related to cognitive and language development in the children at age two; children whose mothers self-reported more stress during the storm had lower MDI and MCDI scores than children whose mothers reported less stress. Furthermore, the authors followed the sample and analyzed the differences between the children in the affected and control groups at five-and-a-half-years-old. Children whose mothers had reported higher stress levels had lower full-scale IQs (Correlation -0.33, $p<0.05$) and weaker language abilities as measured by the Peabody Picture Vocabulary Test-Revisited (Correlation -0.34, $p<0.05$) at age 5 compared to children whose mothers reported no stress (Laplante et al., 2008). These results suggest that the observed differences at birth may lead to longer term issues for exposed infants.

Torche (2011) is one of the authors that follows a large number of students during a short period of time. This author examined the effect of a 2005 earthquake in a remote, northern region of Chile, using a population-based dataset to test the hypothesis that prenatal maternal stress was related to lower birth weight. She used a difference-in-differences regression approach to measure the effect of the earthquake. This methodology compares the performance of the affected group versus the control group, and analyzes the development before and after a random exogenous shock (Abadie, 2005). In this case, the author had two comparison groups; first, impacted infants were compared to infants from regions not affected by the earthquake and, second, a comparison was made to infants from the affected location born in different years. Newborns whose mothers experienced the earthquake (N=1,066) during the first trimester of pregnancy weighed 1.79 ounces less (or 1.5% less) than their 500,000 comparable peers not exposed to the earthquake. Notably, these effects were only found for infants whose mothers were in their first trimester during the earthquake. The infants of 1,087 women who were in the earthquake region during their second trimester and 1,066 women exposed during their third trimester had no differences in birth weight. This research finds that sample attrition (fetal deaths, spontaneous abortions, or miscarriages reported during the period) was small and similar to infants born in other time periods. Therefore, in this sample, stress did not disrupt pregnancy, but was related to lower birthweight of newborns.

While the effects of being exposed to a natural disaster – earthquakes in particular – on birth outcome, neonatal development, and early childhood cognitive and language development are well documented, the long-term implications of these early differences are less clear. Do these early differences persist or are they resolved? Is prenatal stress related to long-term educational attainment? As noted above, at least one investigation showed cognitive differences persisting to age 5 (e.g., Laplante et al., 2008).

Fuller (2014) followed a large number of students during a longer period of time. She studied the effects of natural disasters in North Carolina on birth and educational outcomes. Using a dataset of over 10 million individual test records for over 2.9 million students from third grade her results showed that children prenatally exposed to hurricanes were less likely to perform well in math and reading in third grade. The author used test scores from the end of the academic year finding that prenatal stress is related to a reduction of one standard deviation in primary school reading test scores. Fuller controlled for the age of the students inside the classroom, as other papers in the literature have shown that the age of the students is correlated to their academic performance (Crawford et al., 2014; Fredriksson & Öckert, 2013). Although Fuller used several controls, including the age of the students, one limitation to her research is that it did not address if students of different socioeconomic status (SES) were affected differently by natural disasters. Because low-SES families may have limited access to material and social resources, they may be doubly affected, suffering greater stress at the time of the disaster and needing to rely on lower quality public and private services and social supports in the aftermath (Propper, 2012); it could be the case that mothers from high SES backgrounds may have had better tools to cope with prenatal maternal stress related to natural disasters. The current investigation considers and controls for SES by examining how earthquake exposure in utero may be related to high school academic achievement for children of different SES.

Another potential concern is that while Fuller showed that acute prenatal stress has an adverse effect on educational outcomes through primary school, there is very little research that shows long term effects. According to Bjorklund (2013), although some aspects of cognition are highly stable from childhood into adulthood, this does not mean that cognitive levels are fixed, as cognitive development involves stability as well as plasticity. It could be the case that cognitive effects of prenatal stress are compensated for over time, and that extra effort and the development of abilities, when available, could eliminate these differences. Thus, while there is evidence showing that children who are prenatally exposed to natural disasters show developmental delays during early childhood, most studies have only assessed impact over time of relatively small samples rather than larger population-based data. Large population datasets would allow for detection of smaller systematic differences.

As noted above, previous research has focused on birth outcomes (e.g., full-term vs. preterm birth and infants' weight, birth complications, etc.) and early cognitive development. Long-term follow-up data on children born prematurely suggests lower educational outcomes after 5 to 6 years. However, the disaster follow-up literature does not distinguish between those children born early and those born full term when looking at academic and cognitive differences beyond early childhood.

Reliability problems are due to the use of evaluations that can be of two types: evaluations or scales of maternal stress and evaluations of academic performance or IQ of the children. Both types of measurement evaluations have margins of error that could be affecting the estimations when combined with small sample sizes. Moreover, the outcome variables have yet to prove their significance or importance, as ¼ of standard deviation in a standardized test may not be relevant in terms of academic or labor outcomes (Fuller, 2014; Laplante et al., 2008). In addition, some of these studies have extremely small sample sizes (e.g., Dancause et al., 2011; Dirkzwager et al., 2006; King & Laplante, 2005), raising questions about the reliability and external validity of their results.

Relevance issues arise as these studies analyze the impact of maternal stress due to natural disasters by relying on physiological measures development such as being born small for gestational age (SGA), low birth weight, and hours in ventilators among other outcomes (Currie & Rossin-Slater, 2013; Tan et al., 2009; Torche, 2011a). However, these studies do not have long-term follow-up data on children whose early birth and/or neonatal difficulties are temporally linked to maternal stress. Consequently, these studies lack clarity regarding the relevance of the impact of the natural disaster or the importance of those results for long term outcomes.

To address the relevance of the impact of natural disaster on long term-outcomes, this study uses measures of academic performance that have clear impact in people's lives. In this research a standardized test, high school grades (GPA), and college graduation status are used to evaluate long term outcomes of children whose mothers were exposed to a natural disaster, the Chilean Earthquake, during the target pregnancy. GPA is important as it affects the ability of students to enter higher-paying competitive college majors in Chile; college graduation is relevant as overall, people with college degrees have higher life-long earnings than people who do not earn degrees. To solve the generalizability problem, I use a national-level dataset, because, as these test scores are used for college admission purposes in Chile, they provide evidence of external validity for the results. Poor performance on these measures (GPA, standardized test scores) affects access to higher education, which is a direct predictor of employment opportunities and income potential.

The literature on low-birth weight and small gestational age (SGA) that uses national-level data and robust methodologies found that negative early effects grow smaller when children are followed over time. Bharadwaj et al. (2013) found that low birth weight is associated with higher mortality rates and lower academic performance in Norway and Chile. Using a Regression Discontinuity (RD) design, a regression method that takes advantage of a discontinuity in the assignation rule of intensive health care (i.e., the hospital treated the baby with supplements if the birthweight was less than 2500 grams), the research shows that the long-term effects of low birth weight can be reduced with nutritional supplements and that supplementation improves mortality rates and has been associated with better academic performance at age 10 (Bharadwaj et al., 2013). Lindström and colleagues (2007) use a Swedish national cohort of individuals, finding that moderately preterm and early-term birth accounted for 85% of the risk attributed to future disabilities or persistent illness. The effect of preterm birth was greater in households of low socioeconomic status. (Lindström et al. 2007).

Black et al. (2007) found that for a Norwegian cohort, low-birth weight was associated with lower academic performance and lower earnings at age 21 (Black et al., 2007). Bharadwaj et al. (2018) followed several cohorts of Swedish twins born between 1926 and 1958. These authors found that low-birth weight has negative academic and labor market impacts resulting in lower wages for adults (Bharadwaj et al., 2018). Royer (2009) analyzed the cohorts of singletons and twins born between 1960 and 1982 in California, and posited that lower birth weight was associated with lower educational attainment (as in other samples) but that lower birth weight was also found to predict lower birth weight in the next generation – the offspring of these low birthweight children were also low birthweight (Royer, 2009). Other authors have calculated the long-term economic impacts of low birth weight and SGA, associating them with lower educational attainment, lower labor market participation, and mortality (Alderman & Behrman, 2006; Behrman & Rosenzweig, 2004).

The current study examined the cohort of children born in the months following the 8.0 magnitude earthquake in Santiago and Valparaiso Chile in 1985. Specifically, to investigate the long-term effects of prenatal stress, academic functioning is compared among youth born in the months preceding the earthquake with those born after, and compares young adults who were born in the affected geographic regions with those born in other parts of Chile.

The 1985 Chilean earthquake, ranked as one of the largest in recorded history (Somerville et al., 1991), affected a region that encompassed more than half of Chile's population which was a population of over 12 million at the time; 177 people were killed and another 2,575 people sustained injuries. Furthermore, an estimated 85,358 houses were destroyed and about one million people were left homeless. For women who were pregnant at the time, it can be assumed that this was very stressful.

In Chile, information for all students (enrolled in public and private schools) is available for researchers via vast and open datasets of educational records and attainment, including the mandatory high school standardized SIMCE test scores, high school grades, and college graduation rates. Measurements of the performance of students 16, 18, and 32 years after the earthquake were examined, providing a long-term, longitudinal assessment of educational outcomes of students whose mothers experienced prenatal stress during this event. As the educational datasets in Chile include measurements of month of birth, parental income, family social economic status (SES), these variables were used as controls in the statistical analysis.

It was expected that there would be differences in standardized test scores for children born 18 to 32 weeks after the earthquake, compared to those born either 6 months earlier or 1 year later. It was also expected that the educational outcomes for young adults born several hundreds of miles away from the epicenter would differ from their peers whose mothers were in closer proximity, presumable experiencing greater stress due to the earthquake. The 18 to 32 weeks birth window was necessary because the student database does not include birth history, and it could be assumed that some of the children in the cohort may have either been born prematurely or were small for their gestational age.

Chapter II

Research Method

This study examined national educational records of adolescents born between 1985 and 1991 in Chile. Data from administrative databases of the Ministry of Education of Chile, that include all students in the country – from private and public institutions – that had attended or graduated from high school in Chile were considered. These students all took the national mandatory SIMCE tests. The college graduation status of these students was also considered. These datasets were downloaded from the institutional website of the Research Center of the Ministry of Education https://centroestudios.mineduc.cl and from the Quality Agency https://www.agenciaeducacion.cl of the Ministry of Education.

Participants

Publically available educational records from 322,019 teens born in Chile during the years 1985 to 1991, all of whom were educated in Chile, provided the data for this investigation. Cases were identified using masked social security numbers (SSN) provided by the Ministry of Education of Chile. All the datasets used in this investigation are maintained by the Research Center of the Ministry of Education. Using governmental educational data and the children's dates of birth, the study assumed the students' mothers were pregnant during the earthquake in the impacted regions of the county; the

Metropolitan and the Region 5 of the country were the urban areas that were most impacted by the earthquake.

Exposed Group

The exposed group included over 22,229 teens born between 18 and 32 weeks after the 1985 earthquake and in the geographical areas affected by the earthquake, who attended high school in Chile. The exposed group is compared with two different control groups. Following the example of Torche (2011), two control groups were established.

Control Group I

The first control group included 85,884 individuals born between 18 and 32 weeks after the 1985 earthquake but born outside the affected area (I, II, III, IV, VI, VII, VIII, IX, X, XI, and XII regions, which contain the urban areas not affected by the earthquake) or born outside of the 18- to 32-week post earthquake window.

Control Group II

The second group includes 213,836 individuals born between 1986 and 1991, not affected by the earthquake, but who studied in the same regions and schools as the exposed group. Using these types of control groups is necessary as age of the students (or social age inside the classroom) has an effect on scores and graduation rates that need to be controlled (Crawford et al., 2014; Fredriksson & Öckert, 2013). The use of these two groups ensures the robustness of the estimations, as other shocks could affect individuals born in the same time period of the earthquake, but in different regions.

Measures

The educational achievement of individuals was measured using three academic outcomes.

SIMCE Scores (System of Quality Measurement in Education)

This test is a national mandatory achievement test given to all high school students in the 10th grade in public and private schools in Chile. It has 45 items and takes 90 minutes to complete. Scores have a mean of 250 and a standard deviation of 50 for students taking it during the 2001 school year. The average student performance has been very consistent year to year, with those who were born the year prior to the earthquake and those who were born the following year having very similar average scores. Therefore, for this study, we compared students from the different cohorts using the SIMCE test. The test gathers parental and teacher data, specifically information about the parents' socio-demographic factors such as maternal education, family per-capita income level, and type of school attended, among others.

Grade Point Average

The high school grade point average (GPA) for all four years of high school comes from the Ministry of Education high school graduation datasets. All schools in the country use the same 1-7-point GPA scale. The GPA is available for all students and has been widely used in Chile as a measurement of academic success, a predictor of future performance of students, and as a college selection variable. In this investigation, the GPA was calculated in percentiles, to provide a comparable measure across high schools.

The GPA is used as one of the main college selection variables in Chile, which has a single national system for applying to and being accepted by universities. The GPA is combined with test scores to create an application score used by the national centralized college application system. These college selection scores have been linked to the selection of more competitive major college combinations and higher wages in the labor market (Hastings et al., 2013; Zimmerman, 2019). The high school GPA has been associated with probability of college graduation once students are in college (Bordón et al., 2015).

College Graduation

Graduation records in Chile are organized by the System of Information of Higher Education from the Ministry of Education. This institution has been gathering information from over 170 higher education institutions since 2007. In this research, graduation was considered as a binary variable (composed of “0” if the student has not graduated and “1” if the student graduated), indicating college graduation anytime between 2007 and 2017. The national records indicate that 96,000 students graduated in 2007 and the rate increased to 239,000 by 2017. The total number of students who graduated between 2007 and 2017 is 1,794,606. Time to graduate in higher education varies enormously in Chile; the shortest graduation time for college is four years; however, there are programs that last 5, 6, or even 7 years depending on what a student is studying. For example, in fields like medicine, students do not graduate until they complete the equivalent of medical school in the US. There are some college degrees, such as Law, that are designed with five years of classwork, but the average graduation time is actually 8 years (SIES, 2015). College graduation is a very relevant outcome variables as it has important consequences for the labor market outcomes of students, as college graduates earn twice as much as high school graduates. (SIES, 2015)

In Chile, not all students enroll in college directly from high school and not all students complete their college education in 4 years (Blanco et al., 2018). Therefore, to use college graduation as an outcome variable, it is important to measure students many years after high school graduation (10+), and not only four years after.

The records of graduated students in Chile are currently available online (See Appendix C) and can be directly downloaded. Students' identification information is protected as all datasets use a masked SSN, so that it is possible to merge across all educational datasets.

Control Variables

The SIMCE questionnaires provide self-reported information for parents and students regarding sociodemographic factors such as age, maternal education and family per-capita income level. These variables are used as a control in the regression and allow for a comparison of students with similar characteristics, for example, comparing students whose mothers have similar education, and who are from the same geographical area but have different income levels. The questionnaires of these variables are described in Appendix B.

Research Design

The association of maternal stress due to the earthquake with educational outcomes of the offspring were examined in a 2-group comparison design.

Educational outcomes include SIMCE test results, GPA, and college graduation status was compared for the group impacted by this natural disaster, and the control groups.

Procedure

All data was collected from the official webpage of the Ministry of Education and combined using masked SSNs to create a single dataset. In the final dataset, the exposed group included 22,000 thousand students, and 750,0000 students were used to create the control groups. These data sets were merged to create the control group I and control group II, and obtained a total sample of 322,019 students. In Appendix C, it is specified how datasets were requested and merged.

After consulting with the Committee on the Use of Human Subjects, this research was categorized as “non-human subject” and determined by Harvard’s Data Security Policy as Level 1 Data. Therefore, informed consent was determined to be unnecessary in order to examine these data to test the study hypotheses.

Data Analysis

Data were analyzed using STATA version 16 statistical software. Descriptive statistics were examined in order to check for missing or out-of-range data. ANOVA, OLS (Ordinary Least Squares) and Logistic models were calculated to examine the relationship between exposure to the 1985 earthquake during the prenatal period and high school GPA, SIMCE scores, and college graduation for the control I and control II group versus the exposed individuals.

Hypothesis 1

In order to investigate the relationship between prenatal stress due to the earthquake and academic achievement, ANOVA mean tests was conducted.

A second approach added maternal education and the month of birth as controls to the ANOVA. The age of the students is relevant, as previous studies have shown that older students in the same cohort tend to perform better than the younger ones (Crawford et al., 2014; Fredriksson & Öckert, 2013).

Hypothesis 2

A series of analysis were performed to estimate the relationship between family income, prenatal stress and academic achievements. An ANOVA means test was conducted identifying students from low family income and high family income. Then, multiple regressions analysis was performed to investigate the effects of the control variables, prenatal exposure and family income on the educational outcomes.

Chapter III

Results

After reviewing the demographic characteristics of the sample, analysis of variance and multiple regression were used to test the hypotheses of this study.

Demographic characteristics of the sample

The final sample included 322,019 students born in Chile between 1985 and 1991. The sample was composed of three groups: the exposed group (22,229) and two control groups described below.

The exposed group were young adults who were born between 18 and 32 weeks after the earthquake in the affected regions (Metropolitan and Region 5). There were 11,789 (52.87%) females and 10,510 (47.13%) males, totaling 22,229 individuals. The exposed group is composed of students that took the 10^{th} grade SIMCE test in 2001.

Control group I are students not affected by the earthquake either because they were in different geographical areas or outside of the 18- to 32-week window. Control group I is composed of 46,187 (53.785%) females and 39,697 (46.22%) males, totaling 85,884 individuals. These students also took the SIMCE test in 2001.

Control group II is composed of two cohorts of students that took the 10^{th} grade SIMCE test in 2003 and 2006 (students in years 2002, 2004 and 2005 took the 8^{th} grade test and not the 10^{th} grade test). This group is a sample of students that were born in the regions affected by the earthquake but their gestation was well after the earthquake so their mothers were not exposed to stress during pregnancy (Metropolitan and Region 5).

There were 114,832 (53.70%) females and of 99,004 (46.30%) males, totaling 213,836 students. Combined, both control groups included 161,019(54%) females and 138,701(46%) males, totaling 299,720 students.

Table 1 provides the descriptive characteristics of the exposed group and the control groups. SIMCE scores range from 90 to 450, with a mean on 250 and a SD of 50 points. For the exposed group, the average score in the SIMCE tests in language was 271 points, and the average score in mathematics was 269 points. Students in the exposed group have an average high school GPA ranking of 58% (calculated as percentiles), and 38% of students have graduated from college by 2017. The average maternal education in this group is 10.93 years and the average monthly family income $841.

For control group I, the average score in the SIMCE tests in language is 265 points and the average score in mathematics is 262. Students in control group I have an average high school GPA ranking of 58%, and 37% of students have graduated from college by 2017. The average maternal education is 10.47 years and the average monthly family income is US$ 661. It is worthy to note that the students from control group I tend to come from other regions of the country, and these regions tend to be poorer and have lower educational performance than the area where the earthquake occurred.

For control group II, the average score in the SIMCE tests in language is 267 points and the average score in mathematics is 268 points. These students have an average high school GPA ranking of 57%, and 31% of students have graduated from college by 2017. The average maternal education is 11.19 years and the average monthly family income is US$ 812.

Table 1.

Descriptive Mean Statistics Outcomes, Control Variables and ANOVA

Variables	Exposed	Control I (different area from exposed group)	Control II (same area from exposed group)	Controls I & II
Mathematics Students SIMCE Test Score	268.95	262***	268***	265.95
Language Student SIMCE Test Score	271.38	265***	267*	266***
Standardized High School GPA	58.2%	58%	57%***	57%***
College Graduation	38.4%	37%***	31%***	33%***
Maternal Education in years	10.93	10.47	11.19	10.99
Monthly Household Income (US$)	840.9	662.1	812.1	769.1
Age HS Graduation	17.3	16.99	17.05	17.04

Means test Statistical Difference *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Academic Outcomes

To test the hypothesis that students who were born between 18 and 32 weeks after the earthquake would have lower GPAs, lower SIMCE scores, and would be less likely to graduate from college than matched students not affected by the earthquake, ANOVA was used to compare the outcome variables for the exposed group, control group I, control group II and the two control groups together. Table 1 shows the means of the outcome variables for the exposed group, control group I, control group II, and both control groups together.

Contrary to the expectations, both control groups had lower scores for the SIMCE mathematics and language test scores, as well as for college graduation when compared to the exposed group. The difference between control group I and the exposed group on high school grades is not statistically significant.

Table 1 also shows that the exposed group had higher means across all four outcomes when both control groups are considered together. Moreover, the mean differences between control group I and control II were tested, significance differences in all four outcome variables with the exposed group performing better than the control groups (see Appendix E, Table E.2).

ANOVA analyses were performed to further test hypothesis 1. Tables 2, 3 and 4 display the adjusted means of the exposed group when compared to control group I, control group II and both control groups jointly, including maternal education as a control variable.

Table 2 shows the adjusted means of the ANOVA using control group I and the exposed group, and maternal education as an explanatory variable. In contrast to the prediction, exposed teens scored higher in mathematics and language even after controlling for maternal education levels. However, the results for college graduation for students exposed showed that, as predicted, after controlling for maternal education levels the exposed group was less likely to graduate from college. OLS regressions are added in appendix G showing that exposed children whose mothers that had completed less education, tend to graduate less from college. Therefore, students from less educated mothers, were affected the most by the earthquake.

Table 2

Adjusted Means after ANOVA: Exposed Group and Control I with Maternal Controls

	(1)	(2)	(3)	(4)
VARIABLES	Math.	Lang.	HS GPA	College
Exposed	266.8	269.6	.580	.366
Control I	262.4****	265.9***	.583	.377***

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 3 shows the adjusted means of the ANOVA results comparing the exposed group and the control group II, controlling for maternal education. Exposed students had higher mathematics and language test scores, had higher high school GPAs, and higher rates of college graduation after controlling for maternal education and age.

Table 3

Adjusted Means after ANOVA: Exposed Group and Control II with Maternal Controls

	(1)	(2)	(3)	(4)
VARIABLES	Math.	Lang.	HS GPA	College
Exposed	269.8603	272.05	.5817101	0 .388
Control II	267.49***	266.91***	.568***	.312***

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

The adjusted means of the ANOVA, in Table 4, show that the exposed group had higher mathematics and language test scores, and higher high school GPAs than Control Group I and II. Interestingly, whereas the exposed group was less likely to graduate from college than their same age cohort peers (see above), when and college graduation was considered, the exposed group was more likely to graduate compared to Control Group I and II.

Table 4

Adjusted Means after ANOVA: Exposed Group and Control I & II with Maternal Controls

	(1)	(2)	(3)	(4)
VARIABLES	Math.	Lang.	HS GPA	College
Exposed	269.0	271.47	.5814838	.383
Control I & II	265.9***	266.5***	.573***	.33***

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Tables 5, 6 and 7 display the adjusted means of the ANOVA results that test the main hypothesis of this study, including maternal education and the age of the student. The age of the students is incorporated as a control variable because studies have shown that older students from the same cohort tend to perform better than their peers (Crawford et al., 2014; Fredriksson & Öckert, 2013). As an example, a student born in June would perform better than a student, six months younger, born in December.

The results comparing the exposed group and control group I are displayed in Table 5. Contrary to hypothesis 1, exposed teens have higher mathematics and language scores than students in control group I. As expected, exposed teens have lower high school GPA and lower college graduation rates, compared to their peers in control group I, when controlling for the age of the students and maternal education.

Table 5

Adjusted Means after ANOVA: Exposed Group and Control I with Maternal and Age Controls

	(1)	(2)	(3)	(4)
VARIABLES	Math.	Lang.	HS GPA	College
Exposed	267.8	269.5	.578	.3581208
Control I	262.2***	265.9***	.583***	.386***

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

The ANOVA results between the exposed group and the control II group are shown in Table 6. Contrary to the prediction, the results show the exposed group having higher adjusted means, compared to the control II group in all outcome variables.

Table 6

Adjusted Means after ANOVA: Exposed Group and Control I with Maternal and Age Controls

	(1)	(2)	(3)	(4)
VARIABLES	Math.	Lang.	HS GPA	College
Exposed	268	270	.578	.386
Control I	265***	268***	.567***	.33***

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

The results comparing the exposed group and control group I & II are displayed in Table 7. In line with the hypothesis, the results show that the exposed group has lower GPA and College graduation when controlled by maternal education and age. However, the exposed group performs better than control group I & II in mathematics and language test scores.

Table 7

Adjusted Means after ANOVA: Exposed Group and Control I & II with Maternal and Age Controls

	(1)	(2)	(3)	(4)
VARIABLES	Math.	Lang.	HS GPA	College
Exposed	269	268	.568	.322
Control I	265***	266***	.573***	.334***

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

To better understand the effect of the earthquake on the performance of students, Figures 1 to 4 show the outcome variables and the age of the students at high school graduation. The age of students is a relevant variables as older students in the same cohort usually tend to perform better than younger students (Crawford et al., 2014; Fredriksson & Öckert, 2013). First, in Figures 1, 2 and 3 the exposed group has higher outcomes compared to the control group I for mathematics and language scores and a small difference for high school GPA. In Figures 1, 2 and 4 the exposed group has an upward tendency with age, while the control group I has downward tendency in relation to age of graduation. For Figure 3, high school GPA ranking, both groups have a very small downward sloping tendency with age.

Figures 5 to 8 show the results for the exposed group and control group II, cohorts in 2003 and 2006. For figures 5, 6 and 8 there is a clear upward tendency in all outcomes that is related to the age of the students. Older students would tend to perform better than their classroom peers. This age pattern seems to behave differently for the cohort in 2001 affected by the earthquake, having a smaller slope for this generation. Looking at the

2003 and 2006 curve we would expect exposed older students to obtain higher results compared to their counterparts of the same cohort.

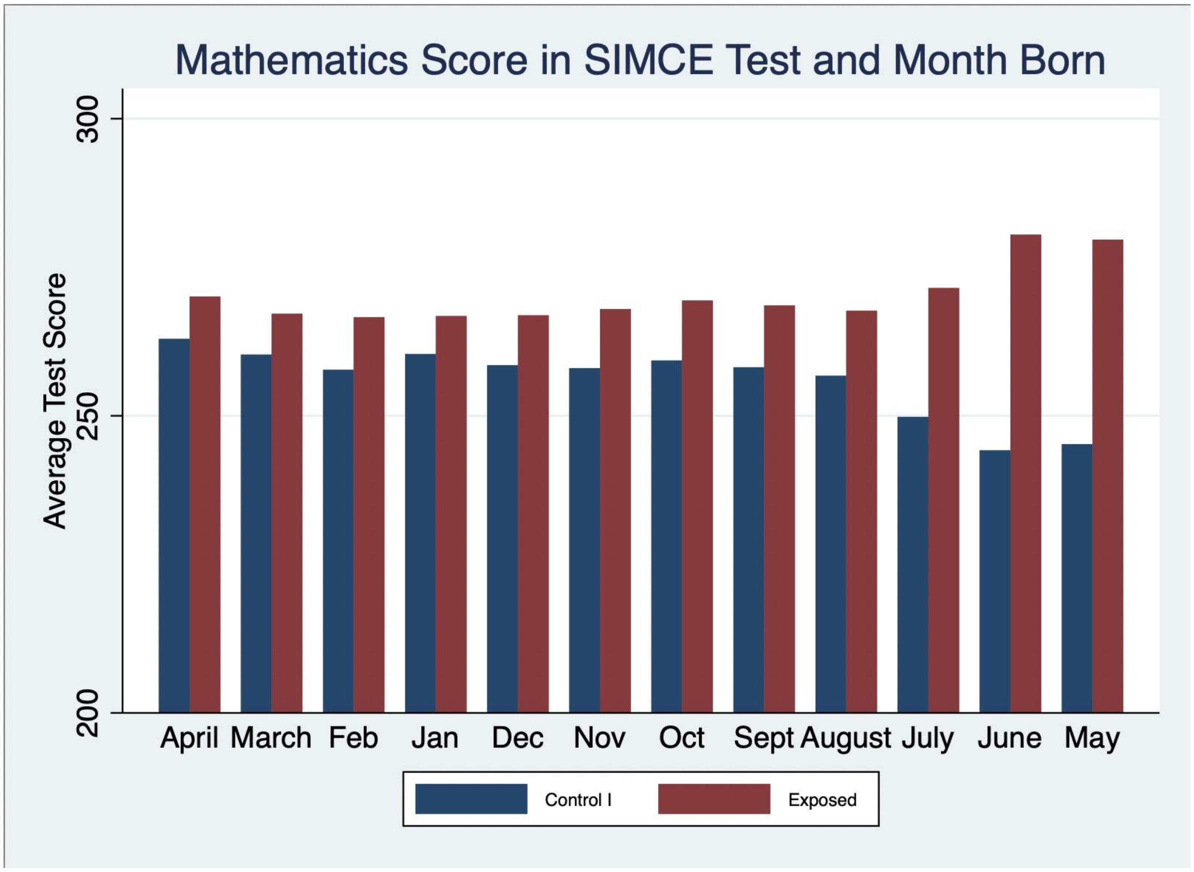


Figure 1. Mathematics Scores in the SIMCE Test exposed and control I: This figure shows the logarithmic polynomial of Mathematic scores in the SIMCE tests of 10th grade and age of graduation for students in cohorts 2001 in the exposed group and the Control group I. Students between the red lines indicate the exposed group for students in the cohort of 2001. SIMCE test scores have a mean of 250 and a SD of 50. For the exposed cohort, older students tend to obtain higher scores in the Mathematic SIMCE test. While for the control I cohort, older students tend to perform worst.

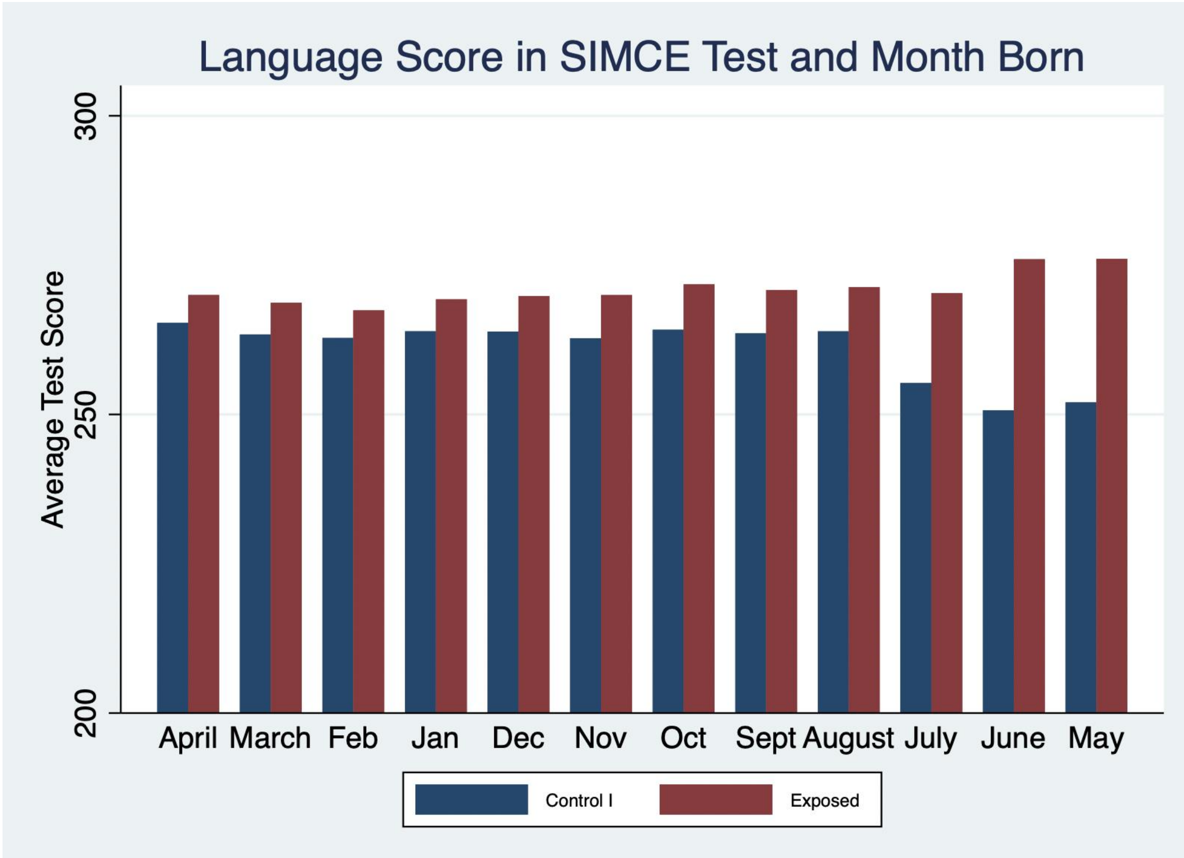


Figure 2. Language Scores in the SIMCE Test exposed group and control group I: This figure shows the logarithmic polynomial of Language scores in the SIMCE tests of 10th grade and age of graduation for students in cohorts 2001 in the exposed group and the control group I. Students between the red lines indicate the exposed group for students in the cohort of 2001. SIMCE test scores have a mean of 250 and a SD of 50. For the exposed cohort, older students tend to obtain higher scores in the language SIMCE test. While for the control I cohort, older students tend to perform worst.

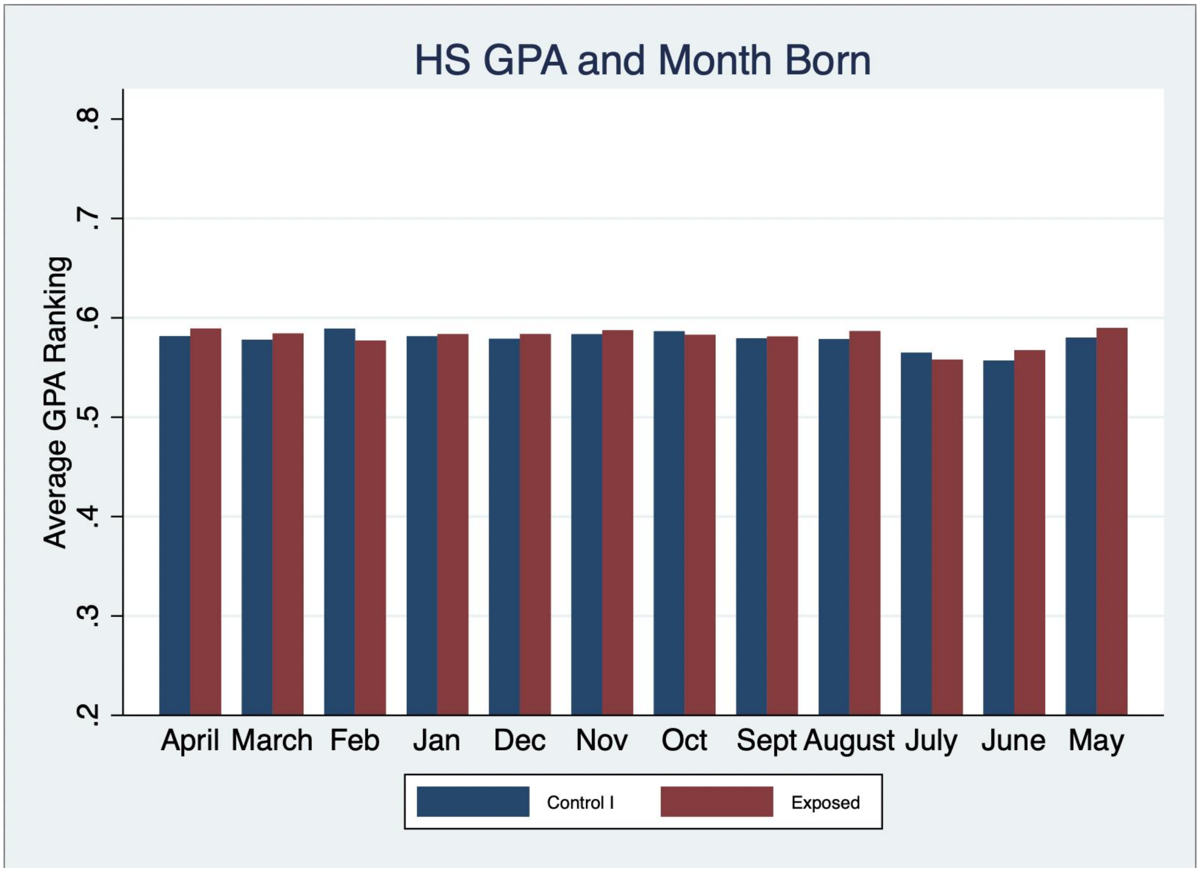


Figure 3. High School GPA Ranking exposed group and control group I: This figure shows the logarithmic polynomial of High School GPA Ranking and age of graduation for students in cohorts 2001 in the exposed group and the control group I. Students between the red lines indicate the exposed group for students in the cohort of 2001. For GPA there is a small tendency of older students obtaining lower GPA

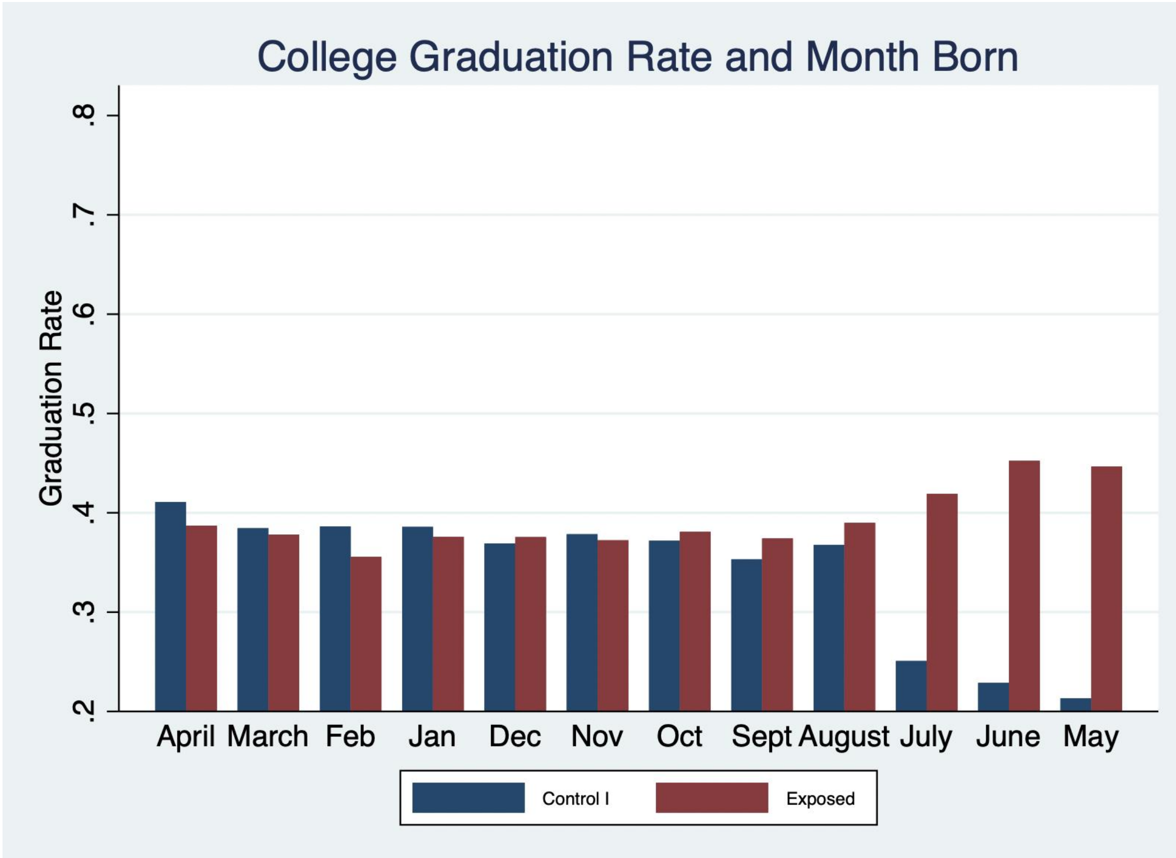


Figure 4. College Graduation Rate by 2017, exposed group and control group I: This figure shows the logarithmic polynomial of College Graduation Rate by 2017 and age of graduation for students in cohorts 2001 in the exposed group and the control group I. Students between the red lines indicate the exposed group for students in the cohort of 2001. For the exposed cohort, older students tend to graduate more from college. While for the control I cohort, older students tend to graduate less.

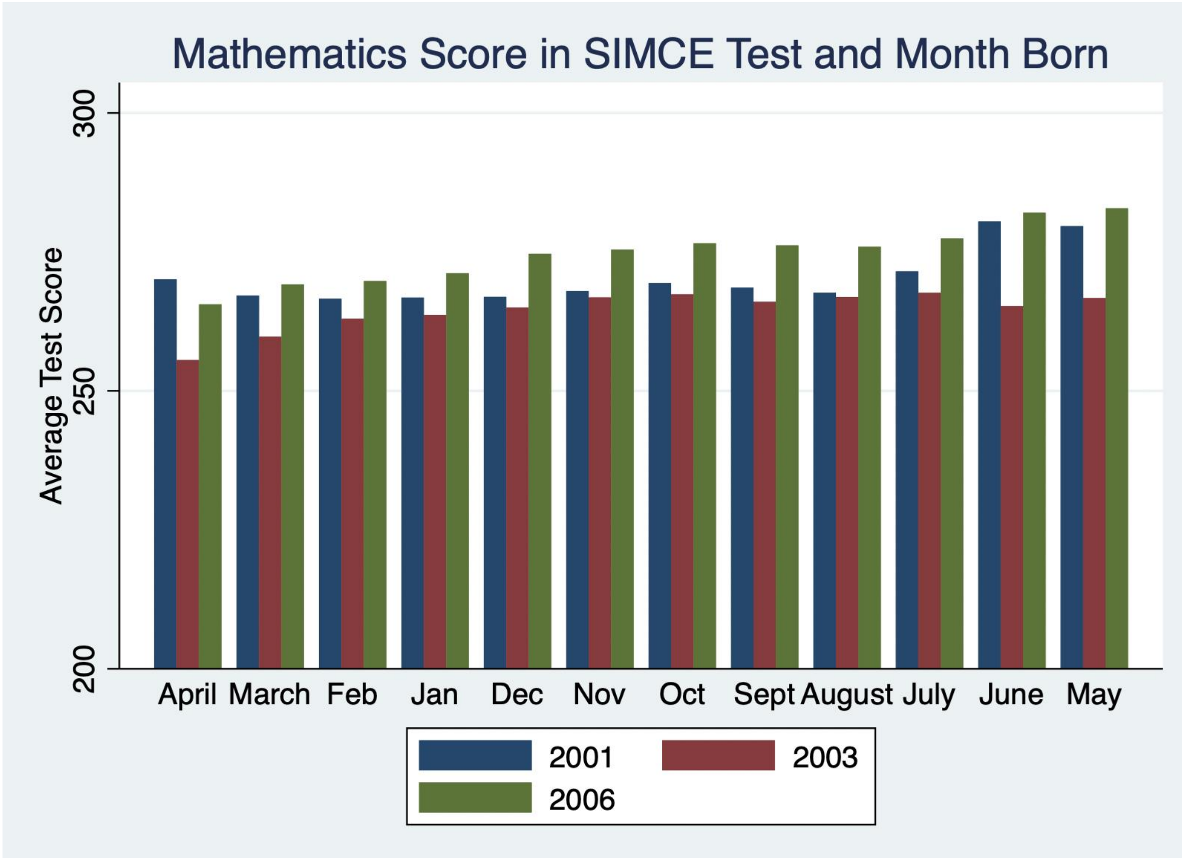


Figure 5. Mathematics Scores in the SIMCE Test, exposed group and control group II.: This figure shows the logarithmic polynomial of Mathematic scores in the SIMCE tests of 10th grade and age of graduation for students in cohorts 2001, 2003 and 2006 in the regions affected by the 1985 earthquake. Students between the red lines indicate the exposed group for students in the cohort of 2001. For the exposed cohort and the control II cohorts, older students tend to have higher Mathematics SIMCE Scores.

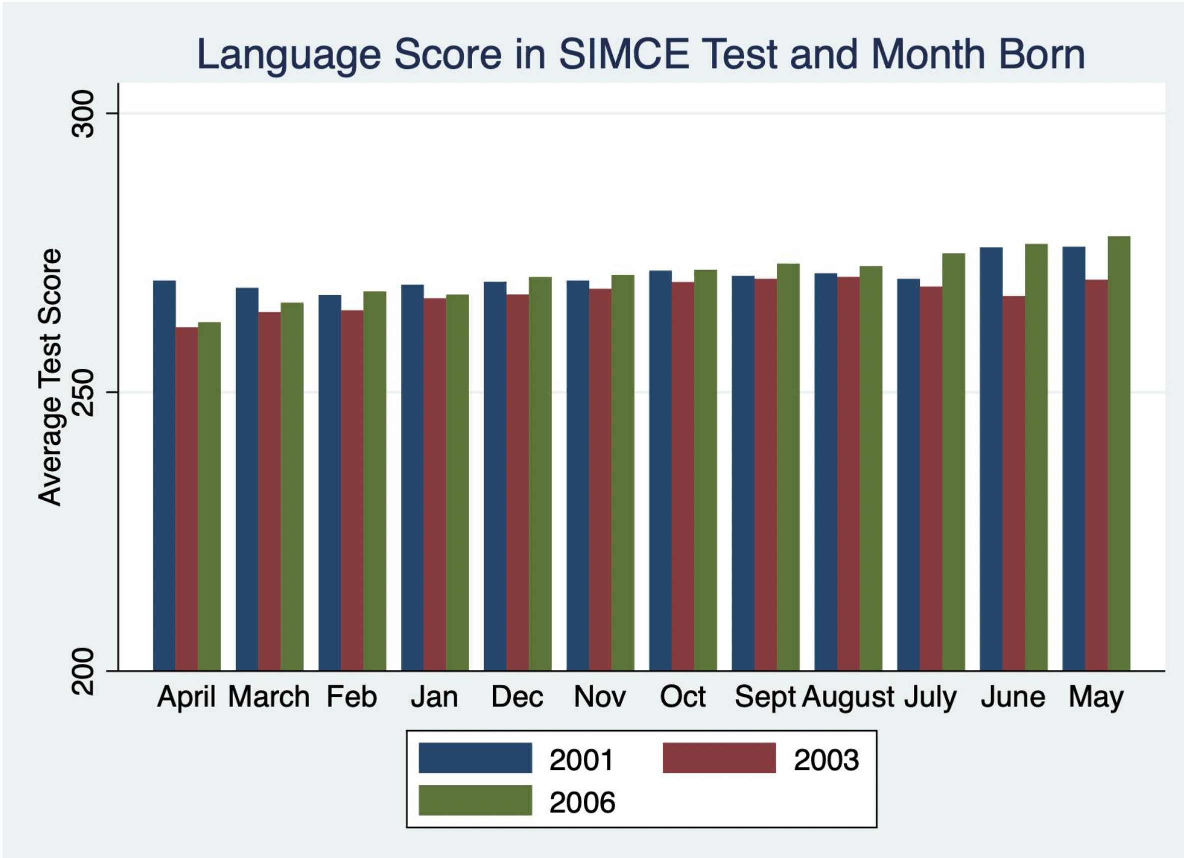


Figure 6. Language Scores in the SIMCE Test, exposed group and control group II. This figure shows the logarithmic polynomial of language scores in the SIMCE tests of 10th grade and age of graduation for students in cohorts 2001, 2003 and 2006 in the regions affected by the 1985 earthquake. Students between the red lines indicate exposed group for students in the cohort of 2001. For the exposed cohort and the control II cohorts, older students tend to have higher Language SIMCE Scores.

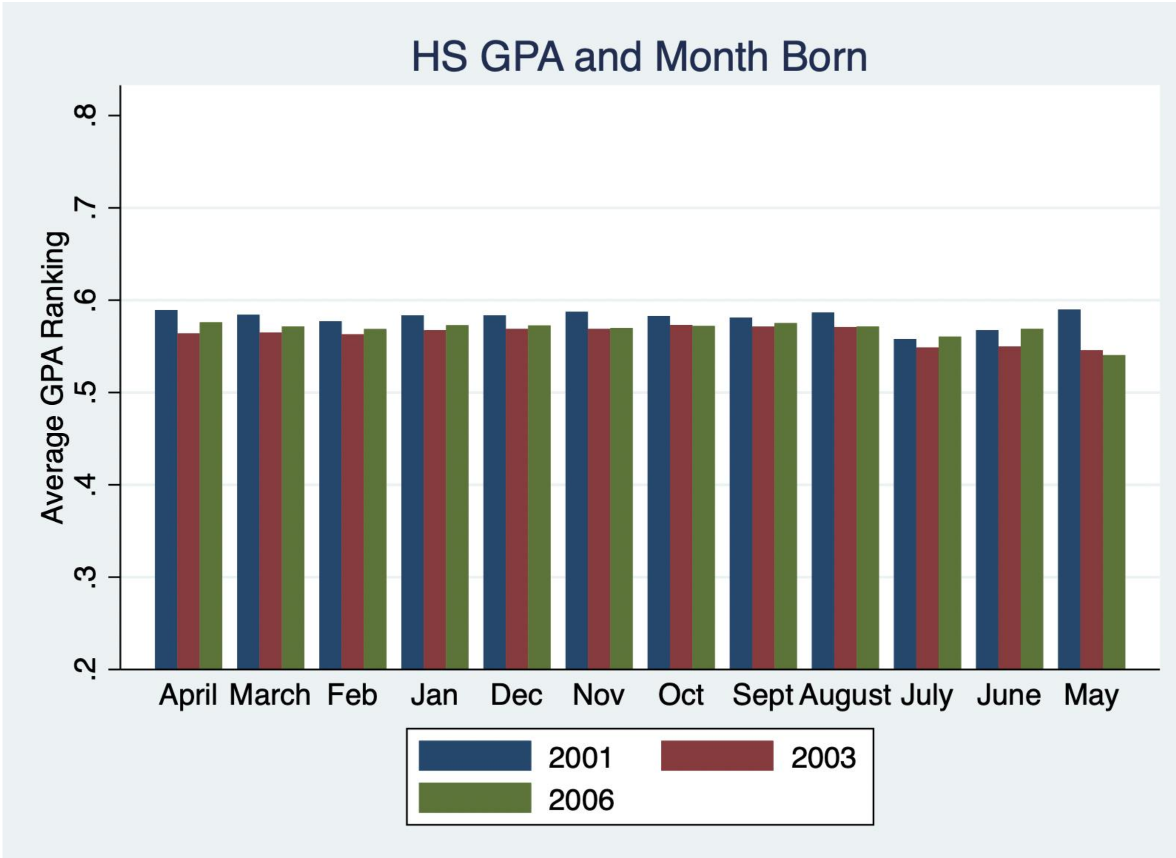


Figure 7. High School GPA Rank, exposed group and control group II. This figure shows the logarithmic polynomial of the high School GPA ranking and age of graduation for students that were in 10th grade in cohorts 2001, 2003 and 2006 in the regions affected by the 1985 earthquake. Students between the red lines indicate the exposed group for students in the cohort of 2001. For the exposed cohort and the control II cohorts, there is a very small pattern of older students presenting lower high school GPA.

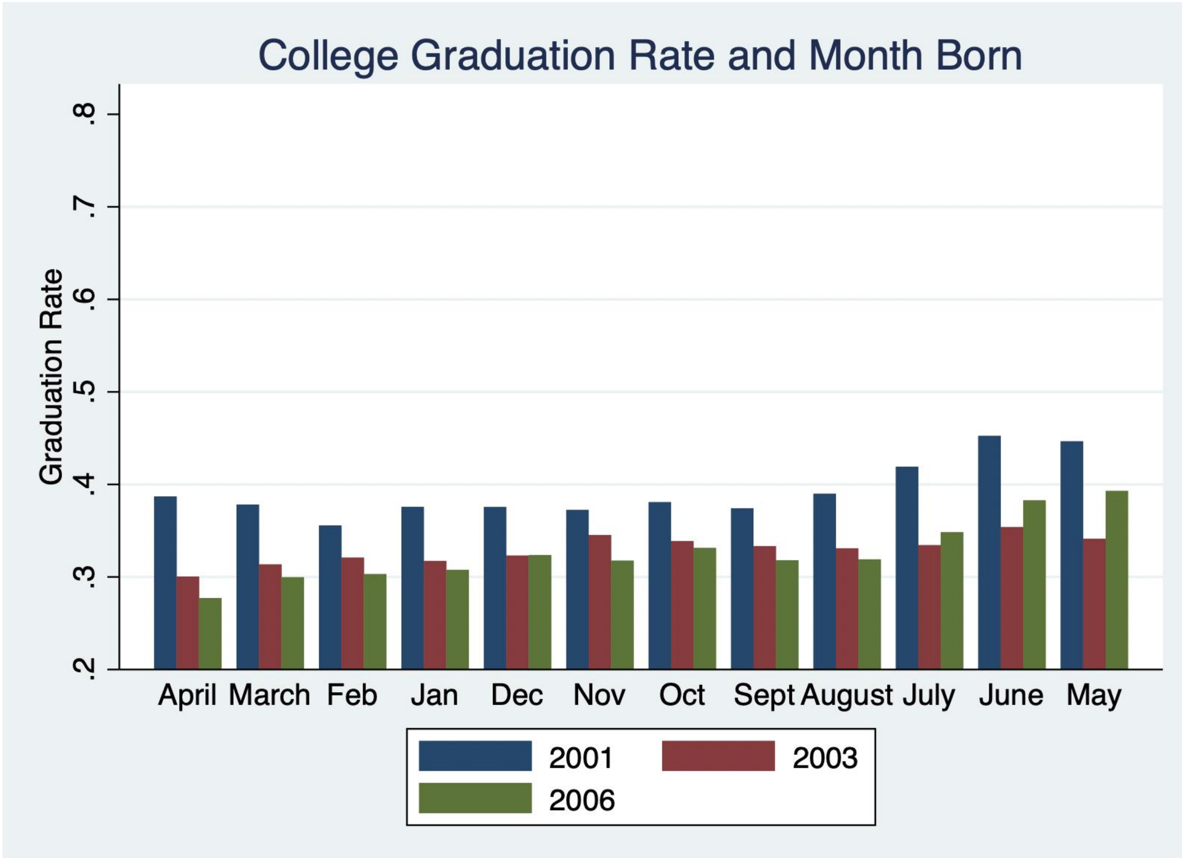


Figure 8. College Graduation Rate by 2017, exposed group and control group II. This figure shows the logarithmic polynomial of the average college graduation rate of graduation for students that were in 10th grade in cohorts 2001, 2003 and 2006 in the regions affected by the 1985 earthquake. Students between the red lines indicate the exposed group for students in the cohort of 2001. For the exposed cohort and the control II cohorts, older students tend to have higher college graduation.

Other Predictors of Academic Outcomes

It was expected that family income would predict test scores, high school performance and college graduation rates in all adolescents, but these effects would be stronger for those whose mothers were exposed to the earthquake prenatally.

The average family monthly income in the sample in 2001 was US$ 699 and the average in the region affected by the earthquake was US$ 816 (statistically different). Students were divided into two groups- roughly the same size -based on their family income: families that were earning over US$400 per month (high income) and families that were earning less than US $400 per month (low income).

Table 8

ANOVA Mean Test Results Low Income Families (less than US$ 400 a month)

	Exposed	Control I (different area from exposed group)	Control II (same area from exposed group)	Both Control Groups
SIMCE Mathematics	245	244**	246*	245
SIMCE Language	254	252***	252**	252***
HS GPA	58%	57%*	56%***	57%***
College Graduation	.195	.22***	.173***	.189

Note: Statistical Differences between exposed and control groups: *** p<0.01, ** p<0.05, * p<0.1

The ANOVA for low income students is presented in Table 8. Contrary to the expectations, among the lower income families, exposed students had higher mathematics and language scores and GPAs than the control students. As expected, the exposed low-income students have a lower college graduation rate, compared to the control group I. Table 8 also shows the results between the exposed group and control group II. The ANOVA results displays that in this lower income cohort, the exposed group had lower mathematics test scores. However, they had higher language test scores, GPA and college graduation compared to control group II. When the two control groups are combined, a comparison between the exposed group and control groups I & II finds higher language scores and GPA for the exposed group.

Table 9

ANOVA Mean Test Results High Income Families (more than US$ 400 a month)

	Exposed	Control I (different area from exposed group)	Control II (same area from exposed group)	Both Control Groups
SIMCE Mathematics	292	286**	286***	286***
SIMCE Language	288	284**	280***	281***
HS GPA	59%	60%***	57%***	58%***
College Graduation	.58	.58	.43***	.47***

Note: Statistical Differences between exposed and control groups: *** p<0.01, ** p<0.05, * p<0.1

Among higher income students, as shown in Table 9, exposed students performed better than or similar to the control groups in all cases, except in high school GPA when compared to control group I. The average of college graduation and family income level can be observed in Figure 9. This graph shows that control group I has a higher college graduation rate, compared to the exposed group for each income level.

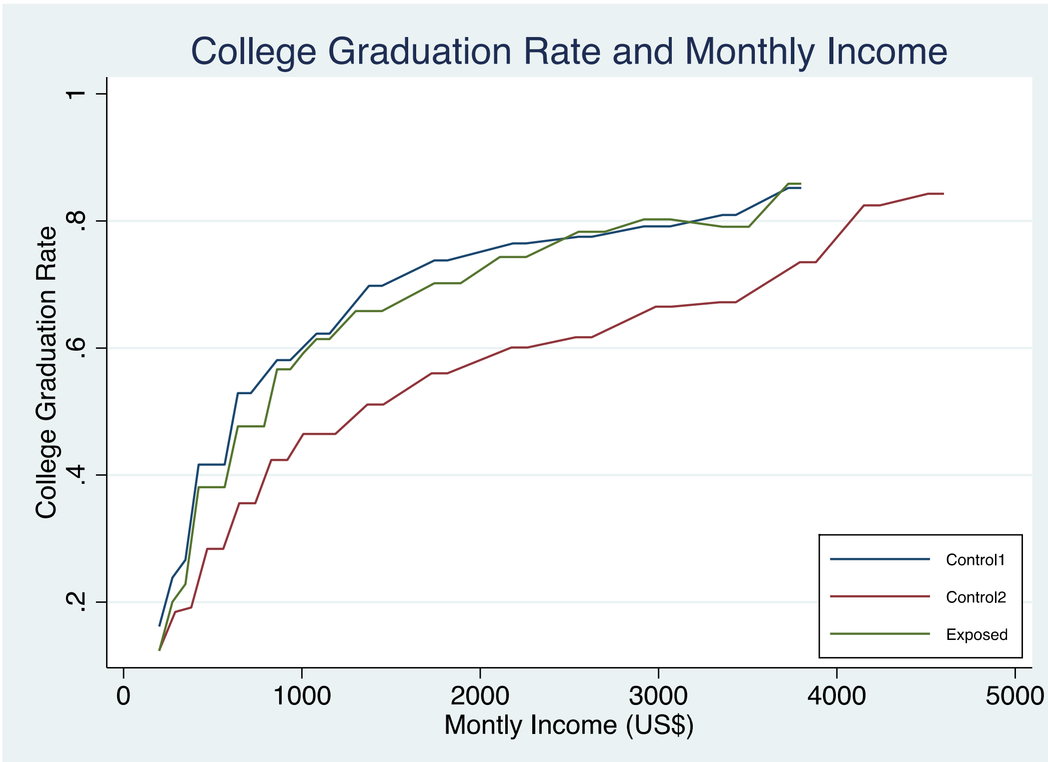


Figure 9. College Graduation Rate by 2017, monthly income, exposed group, control group I and control group II. This figure shows the logarithmic polynomial of the average college graduation rate of graduation and the family income.

To further test hypothesis 2, OLS regressions were performed analyzing in the same regressions exposed students from low-income families and exposed students from high income families. Table 10, 11 and 12 present the results for the regressions including the family income. In table 10, the results show that lower income students tend to have mixed impacts on the SIMCE test of mathematics and language and positive results for college graduation.

Table 11 displays the regressions for the exposed group and control group II; it shows that lower income students born in June tend be more affected in the SIMCE mathematics and language test. The results display also negative findings for college graduation for students born in June, August, and September. On the contrary, higher income impacted students only show a negative impact for GPA, while showing positive impacts for students born in June for mathematics, and college graduation. These results would point out that higher income families were less affected by the earthquake or that their effects were remediated in the long term, while for lower-income families this negative effect persisted during the years.

Table 12 displays the regression for the exposed group and control group I & II. Consistent with the hypothesis 2, low income students are less likely to graduate from college. The regression shows for exposed low-income students, lower college graduation rates for students born in June, August, and September. Moreover, the regressions show negative results for exposed lower-income students born in June for mathematics and language scores. Female students have lower mathematics test scores, but higher language scores, GPAs and college graduation rates.

Table 10.

OLS and Logistic Regressions of Exposed Group, Control I and Income Interaction

	(1)	(2)	(3)	(4)
VARIABLES	Math.	Lang.	HS GPA	College
Exposed Lower Income - born June	-5.052***	-3.945**	0.000541	0.00495
	(1.871)	(1.770)	(0.0111)	(0.0170)
Exposed Lower Income - born July	1.357	0.592	0.0134**	0.0169*
	(1.089)	(1.030)	(0.00648)	(0.00991)
Exposed Lower Income - born August	0.229	0.295	0.00213	0.00419
	(1.064)	(1.007)	(0.00634)	(0.00968)
Exposed Lower Income - born September	2.073**	1.341	-0.00196	-0.00682
	(1.042)	(0.986)	(0.00621)	(0.00948)
Exposed Higher Income - born June	6.252***	3.316	-0.0660***	0.0813***
	(2.391)	(2.262)	(0.0142)	(0.0218)
Exposed Higher Income - born July	1.570	2.067	-0.0216**	0.0277*
	(1.721)	(1.629)	(0.0102)	(0.0157)
Exposed Higher Income - born August	2.519	-0.337	-0.0151	0.0363**
	(1.688)	(1.597)	(0.0100)	(0.0154)
Exposed Higher Income - born September	-0.923	-1.801	-0.0358***	0.00396
	(1.594)	(1.509)	(0.00949)	(0.0145)
Female	-11.82***	7.518***	0.0602***	0.0677***
	(0.287)	(0.272)	(0.00171)	(0.00261)
Constant	216.9***	217.1***	0.472***	-0.00900
	(2.220)	(2.101)	(0.0132)	(0.0202)
Observations	108,183	108,183	108,183	108,183

Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

Table 11.

OLS and Logistic Regressions of Exposed Group, Control II and Income Interaction

	(1)	(2)	(3)	(4)
VARIABLES	Math.	Lang.	HS GPA	College
Exposed Lower Income - born June	-5.288**	-5.641***	0.00602	-0.158***
	(2.548)	(2.123)	(0.0131)	(0.0577)
Exposed Lower Income - born July	0.772	0.954	0.00713	0.0356
	(1.901)	(1.584)	(0.00980)	(0.0334)
Exposed Lower Income - born August	0.0575	0.0184	-0.00377	-0.0613*
	(1.893)	(1.577)	(0.00976)	(0.0333)
Exposed Lower Income - born September	1.667	1.897	0.00143	-0.0786**
	(1.882)	(1.568)	(0.00970)	(0.0330)
Exposed Higher Income - born June	6.056**	0.836	-0.0393**	0.131*
	(3.030)	(2.524)	(0.0156)	(0.0794)
Exposed Higher Income - born July	2.038	2.798	-0.00565	0.0874
	(2.394)	(1.994)	(0.0123)	(0.0614)
Exposed Higher Income - born August	3.772	-0.0564	0.00186	0.0671
	(2.371)	(1.975)	(0.0122)	(0.0607)
Exposed Higher Income - born September	-0.262	-0.907	-0.0106	-0.0207
	(2.287)	(1.905)	(0.0118)	(0.0580)
Female	-11.17***	6.900***	0.0649***	0.251***
	(0.225)	(0.187)	(0.00116)	(0.00581)
Constant	226.5***	230.4***	0.499***	0.0550***
	(2.368)	(2.021)	(0.0126)	(0.0189)
Observations	236,135	236,135	236,135	236,135
R-squared	0.225	0.177	0.017	0.183

Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

Table 12.

OLS and Logistic Regressions of Exposed Group, Control I & II and Income Interaction

VARIABLES	(1) Math.	(2) Lang.	(3) HS GPA	(4) College
Exposed Lower Income - born June	-6.862***	-5.588***	0.00903	-0.147**
	(2.231)	(1.916)	(0.0119)	(0.0676)
Exposed Lower Income - born July	1.163	0.903	0.0134**	0.0579*
	(1.132)	(0.972)	(0.00604)	(0.0306)
Exposed Lower Income - born August	-0.542	-0.108	-0.0118*	-0.0456
	(1.132)	(0.972)	(0.00605)	(0.0314)
Exposed Lower Income - born September	1.103	1.090	0.000796	-0.116***
	(1.102)	(0.946)	(0.00589)	(0.0312)
Exposed Higher Income - born June	4.748**	0.00859	-0.0345***	0.0179
	(2.032)	(1.745)	(0.0109)	(0.0588)
Exposed Higher Income - born July	2.474**	2.372**	-0.00931	-0.0145
	(1.190)	(1.022)	(0.00635)	(0.0393)
Exposed Higher Income - born August	3.581***	0.932	0.00280	-0.0604
	(1.147)	(0.985)	(0.00613)	(0.0385)
Exposed Higher Income - born September	2.891***	1.962**	-0.0110*	-0.0669*
	(2.287)	(1.905)	(0.0118)	(0.0580)
Female	-11.29***	7.121***	0.0638***	0.244***
	(0.186)	(0.159)	(0.000991)	(0.00495)
Constant	217.3***	220.6***	0.483***	-1.607***
	(1.776)	(1.525)	(0.00948)	(0.0538)
Observations	322,019	322,019	322,019	322,019

Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

Chapter IV

Discussion

This study investigated the effect of prenatal exposure to stress from a natural disaster on long-term educational outcomes of the offspring, comparing the cohort of children born in the months following the 8.0 magnitude earthquake in Santiago and Valparaiso, Chile in 1985, to two control groups. It was predicted that offspring of mothers that lived through an earthquake during their pregnancies would have poorer academic achievement. Previous research has linked prenatal stress to lower birth weight, lower gestational age, and lower educational outcomes for young children. However, most research had used small sample sizes (King & Laplante, 2005), followed students during short periods of time (Torche, 2011), or used standardized tests rather than school based measures (Fuller, 2014) that may not correlate with long term life disadvantages.

The research used two control groups. The first control group was students from the same age cohort who were born in regions of the country unaffected by the earthquake. The second control group was students from the same regions, but born in different years, and therefore, not affected prenatally by the earthquake. Outcome variables, were SIMCE test scores, high school GPA and college graduation rates. While the SIMCE tests does not have real life consequences for the students, the high school GPA is one of the variables used in college selection system in Chile. Moreover, college graduation is an important outcome variable as it predicts the future occupation and labor market options for these young adults.

Results did not support the hypotheses overall and students affected by the earthquake, when considered as a single cohort, actually had better rather than worse scores on all four outcomes variables: SIMCE math, SIMCE language, GPA and college graduation rates. However, lower outcomes in mathematics and language tests and college graduation rates were observed among the exposed cohort once students' age and family income were considered.

General Discussion

It was predicted that exposed students would do worse on all four outcomes, nevertheless, this prediction was not supported by the data. However, once age and maternal education and family income was considered, the results are more complex. When maternal education was included as a control variable, college graduation rates were lower for the exposed group when compared to control group I (students in the same age cohort from unaffected geographic regions). Suggesting that maternal education, interacts with exposure, and children from less educated mothers are affected the most.

The comparisons between the exposed group and control group, without any controls, show that the exposed group had better outcomes in language and mathematics test scores, null results for high school GPA and better results for college graduation. This last outcome could be driven by the fact that the affected regions are also in the largest and richest urban areas of the country, which offer higher educational opportunities, that is also where most of the colleges are located in the country (SIES 2015); control group I is composed of students from lower income cities and rural areas, where there are fewer high-quality schools and colleges. While using a cohort from the same age group in an area of the country not exposed to the earthquake made sense logically, in practical concerns the regions may have been too different to provide a robust test of the primary hypotheses; income and proximity to universities may be a more important predictor of educational outcomes than earthquake exposure.

The ANOVA between the exposed group and control group I, controlling for maternal education, showed that students prenatally affected by the 1985 earthquake had higher test scores in the SIMCE test of language and mathematics and but lower college graduation rates. These results persist even when age is included as a control variable. The results also show children from less educated mothers are affected the most by the earthquake. The ANOVA between the exposed group and control group II, showed that the exposed group outperformed control group II in all outcome variables.

The visualization of the results in Figures 1 to 4 show the outcomes of students in the affected and the non affected regions. The results show that the outcome variables of the exposed group and control group I have different patterns after controlling for age. The exposed group outperformed control group I across outcome variables. And, there was a completely different pattern regarding age, with positive slopes for mathematics, language and college graduation showing that older students had higher scores on all three measures. The figures also showed a completely different age behavior between students in the center regions and the control group I. This would mean that exposure to the earthquake is not associated with these differences, but rather that the groups are dissimilar in other systematic ways. Using a contemporaneous cohort from a different region makes sense as a comparison group, but, in this research control group I was composed of students in rural areas and cities that are very different from the two affected regions. Future research should include a control group from a different geographical region better matched in terms of SES and in terms of proximity to major educational institutions.

On the other hand, Figures 5 to 8 display the data comparing the exposed group with control group II, students from the same cities but from different age cohorts, showing broadly similar patterns of results and similar patterns of age, with the exposed group having a lower slope by age indicating a small change in the pattern of performance.

We also examined family income as a factor that might interact with the effect of the impact of the earthquake on academic outcomes. When the sample was divided into higher income and lower income students there were no differences in mathematics and language scores or high school GPA between affected and unaffected students (in all cases, students form higher income families did better than those from lower income families). However, after controlling for income, control group I had a higher college graduation (22%) than the exposed group (19.5%). Thus, prenatal exposure did predict a lower (2.5%) likelihood of graduating from college within the 2001 cohort. This 2.5% of difference seems meaningful, as the college graduation rate of low-income students is on average only 19.5%.

When considering student from the affected regions only, the results show that the earthquake had a stronger effect on students from lower-income families, while students from higher-income families were relatively spared, supporting the hypothesis that lower-income families would be more affected by prenatal stress due to the earthquake. During an emergency, higher income families may have more options; they have more economic and social resources, whether to use for housing, to leave the region until power is restored, to rebuild and to obtain medical services. Moreover, probably the whole reconstruction process is less stressful for families that have the financial resources to recover. Higher income families also have more access to remedial actions after the child is born, should she/he be born early, be low birthweight, or experience other complications that are more likely following a major life stressor. Future research could analyze how higher income families have addressed prenatal stress effectively.

Controlling for age (month born, age relative to same grade peers) proved relevant to identify effect of the earthquake, as not all prenatally exposed students are affected to the same degree. This methodology showed that the exposed group did relatively worse in terms of mathematic and language test scores and college graduation rates. This would mean that prenatally affected students perform worse than expected when compared to their same aged peers. These results are particularly relevant for individuals from lower income families, as this effect is not detected for students from higher income families.

The results of this research support other well documented findings that prenatal stress can have long-term consequences on the educational trajectories of students, Further research should address these results and confirm them in different countries and contexts.

Limitations and Future Research Directions

This research has several limitations. The first one is that this investigation was not able to consider individual factors such as the birth weight r length of gestation. Therefore, there is not a direct connection between specific birth outcomes associated with prenatal stress and specific educational outcomes; all results presume that some portion of the cohort would have the conditions known to be more likely in babies born to mothers who experienced the stress of the earthquake. A second limitation is that this investigation did not control for remedial interventions that parents may have used to increase the outcome for their children (e.g., tutoring, early intervention, physical therapy, etc). Third, although there is information regarding the place of birth of the students, this research does not discriminate which students were the offspring of mothers who experienced the most stress during the earthquake.

Importantly, the sample of students analyzed corresponds to students old enough to take the SIMCE test in 10th grade who were on track based on their age, that is it did not include students who may have dropped out of school, repeated a grade or were otherwise further behind their peers academically. Therefore, this analysis does not include those most severely affected by the earthquake. Hence, the study does not consider pregnancies disrupted by miscarriage (the most severe negative outcome to pregnancy stress possible), individuals born prematurely enough not to survive, the ones who died shortly after birth or during early childhood, or that had severe academic or emotional challenges and were not in the college bound cohort at all, or those who dropped-out of high school before 10th grade.

Lastly, the data were analyzed using students from other cohorts as controls. However, these control subjects also could have been affected by variables not considered in this study. Future research should address the current limitations, providing surveys for mothers affected by natural disasters, recording birth data and following students during long periods of time.

Conclusions

Prenatal stress has been well documented to affect birth outcomes and early educational performance of individuals (Dancause et al., 2011; Fuller, 2014; Laplante et al., 2008; Torche, 2011). However, this study did not show that prenatal stress caused by a natural disaster has long-term consequences in educational outcomes, suggesting that while prenatal stress is a risk factor, the majority of exposed people do not experience long term negative effects.

While this may be true overall, however, among a lower income cohort the effects are more likely to persist. Among this lower income group, there is a negative effect on their educational outcomes. They have lower test scores in 10^{th} grade than their peers, and they are less likely to graduate from college. These results show that income inequality is likely to exacerbate the negative impacts of negative shocks. Prenatal stress, a stressor that for many has short term impacts, has longer term effects for those with fewer resources.

Appendix A

Birth Distribution in Chile

The Chilean Ministry of Health has tabulated the distribution of births in Chile by weeks of pregnancy for year 2013. Offspring born between 32 to 42 weeks of gestation represent 98.5% of births in Chile.

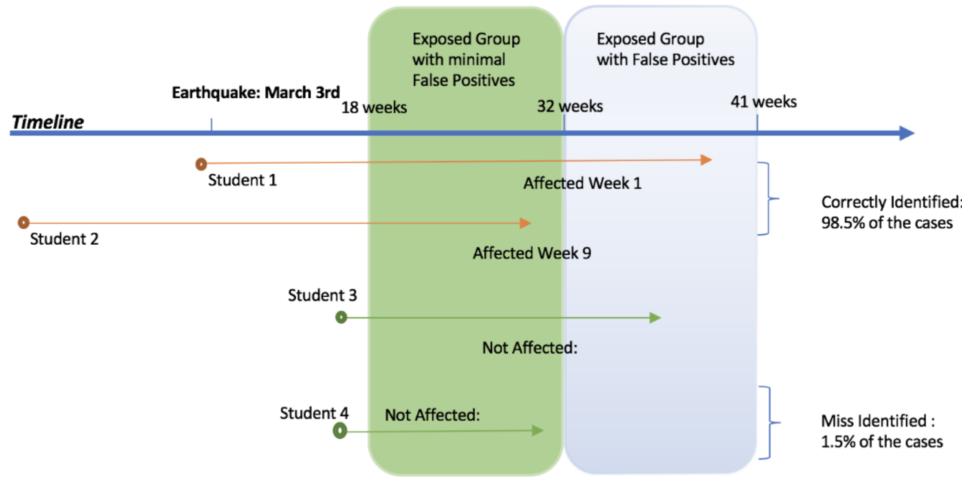
Table A.1 Children born alive in Chile according to gestational age (2013). Ministry of Health, Chile.

	Total	**less 24 weeks**	**24 to 27 weeks**	**28 to 31 weeks**	**32 to 36 weeks**	**37 to 41 weeks**	**42 weeks or more**	**unknown**
Number	242,005	285	797	1,992	15,683	222,568	281	399
Percentage	100.0%	0.1%	0.8%	0.8%	6.5%	92.0%	0.1%	0.2%

If this time window is considered for the exposed group, only 1.5% of births would have not been affected by the earthquake, assuming that the birth pattern did not change much in Chile (Figure A). The use of control groups that were not affected by the earthquake but also have the same proportion of gestational time will allow me to control for this 1.5% of false positive students.

This exposed group could include a small proportion of students that are “false positives,” but were actually born at a prenatal age of 31 weeks or less, and therefore were not affected by the earthquake. False positives could downward bias the regression estimates, making it harder to find statistically significant results. The size of the false positives is small (1.5% of the population).

Figure A.1: Timeline of Children Affected by the Earthquake and Exposed Group.



Appendix B

Summary of Outcome and Control Variables

Outcomes	Description	Min	Max
SIMCE	National mandatory evaluation test, with math and language scores.	60	419
GPA	Average high school grades, grades 9-12	4	7
College Graduation	If the student graduated from college or not.	0 (no graduation)	1 (graduated)
Controls			
Family income	Total self-reported family monthly income in US$.	0	13
Maternal education	Number of years of mother's education, in years.	0	26
Type of school attended	There are three types of schools according to their ownership: (1) public, (2) private voucher, and (3) private paid.	1	3
Number of family members	Number of family members who live in the same home.	0	15
Region	School's geographical region	0	13

Appendix C

Datasets from the Chilean Government

The Chilean government has a policy of open datasets in the educational sector. The only problem regarding data access is not obtaining datasets but rather merging them together. For this research, there is one agency that provides information, thus one research center — the Research Center of the Ministry of Education of Chile — that acts as a hub providing the three types of datasets with common IDs, allowing for the ability to merge them.

High School GPA es and College Graduation:

The databases of students' high school grades and confirmation of college graduations can be downloaded directly from the Research Center of the Ministry of Education of Chile. https://centroestudios.mineduc.cl

SIMCE Test Scores:

The databases of the SIMCE test scores are requested via an online form. In this form, it is necessary to specify that the datasets need to have masked IDs called MRUNs.

http://formulario.agenciaeducacion.cl/solicitud_cargar

Appendix D

Original Income and Educational Questions in Spanish

Pregunta 5	En un mes normal, el ingreso económico del hogar donde vive el alumno está:	1 = bajo $100.000 2 = entre $100.000 y 200.000 3 = entre $201.000 y 300.000 4 = entre $301.000 y 400.000 5 = entre $401.000 y 500.000 6 = entre $501.000 y 600.000 7 = entre $601.000 y 800.000 8 = entre $801.000 y 1.000.000 9 = entre $1.001.000 y 1.200.000 10 = entre $1.201.000 y 1.400.000 11 = entre $1.401.000 y 1.600.000 12 = entre $1.601.000 y 1.800.000 13 = sobre $1.800.000 Blanco No responde
Pregunta 8	¿Cuál es el último año que aprobó la Madre del alumno? Entre 11 y 89 (El 1er digito del número a generar indica el nivel educacional y el 2do el curso.	11-18 = de Educación Básica o Preparatoria 21-24 = de Educación Media Científico Humanista o Humanidades 31-35 = de Educación Media Técnico Profesional o Vocacional 41-49 = en un Centro de Formación Técnica 51-59 = en un Instituto Profesional 61-69 = en la Universidad 71-79 = de Magister 81-89 = de Doctorado Blanco No responde

Appendix E

Demographic Characteristics

Table E.1

Demographic Characteristics of Exposed Group, Control Group I, and Control Group II

	Exposed Group			
Month Born	Male	Female	Total	Percentage
6	618	680	1,298	6%
7	2,282	2,604	4,886	22%
8	2,425	2,642	5,067	23%
9	2,554	2,909	5,463	24%
10	2,631	2,954	5,585	25%
Total	10,510	11,789	22,299	100%

	Control Group I				Control Group II			
Month Born	Male	Female	Total	Percentage	Male	Female	Total	Percentage
1	4,467	5,090	9,557	11%	8,045	9,430	17,475	8%
2	3,917	4,375	8,292	10%	7,150	8,459	15,609	7%
3	4,000	4,641	8,641	10%	7,510	8,913	16,423	8%
4	3,349	3,872	7,221	8%	8,012	9,245	17,257	8%
5	3,158	3,593	6,751	8%	8,224	9,523	17,747	8%
6	2,239	2,848	5,087	6%	8,257	9,412	17,669	8%
7	2,100	2,566	4,666	5%	8,396	9,650	18,046	8%
8	2,408	2,610	5,018	6%	8,555	10,058	18,613	9%
9	2,450	2,763	5,213	6%	9,080	10,107	19,187	9%
10	2,530	2,873	5,403	6%	9,090	10,633	19,723	9%
11	4,642	5,579	10,221	12%	8,367	9,670	18,037	8%
12	4,437	5,377	9,814	11%	8,318	9,732	18,050	8%
Total	39,697	46,187	85,884	100%	99,004	114,832	213,836	100%

Table E.2

ANOVA Mean Different Test Results

	Difference	Control I (different area from exposed group)	Control II (same area from exposed group)
SIMCE Mathe.	5.72***	262	268
SIMCE Lang.	1.57***	265	267
HS GPA	-1.37%***	58%	57%
C. Graduation	-5.86%***	37%	31%

Note: Statistical Differences between exposed and control groups: *** p<0.01, ** p<0.05, * p<0.1

Appendix F

Definitions

Prenatal stress: exposure of pregnant women to external stressors including that from natural disasters.

Chronic stress: long-term stress, specifically in this case of a response to a prolonged period in which individuals sense that they have little or no control. Typically, it involves an endocrine system reaction, in which corticosteroids are released.

Acute Stress: Acute stress is short-term stress, that causes an increase of the nervous system and stress hormones such as cortisol and adrenaline. It is commonly caused by an extreme traumatic stressor. Its symptoms include severe anxiety, dissociation, problems sleeping, mood swings, nightmares, irritability and aggression.

Low birth weight: a birth weight less than 2,500 grams (5 pounds, 8 ounces) (ICD-10, 1990)

Very low birth weight: a birth weight less than 1,500 grams (3 pounds, 4.9 ounces). (ICD-10, 1990)

Gestational age: the age of an individual from conception to birth. It is estimated from the first day of the woman's last menstrual cycle to the date of the birth, usually counted in weeks.

Academic outcomes: a student's academic achievement. Standard indicators of academic achievement are cumulative grade point average (GPA), standardized test scores and college graduation.

Natural disaster: a significant adverse event developed from a natural process of the Earth; examples include snow storms, blizzards, floods, tornadoes, earthquakes, tsunamis, volcanic eruptions, and other geologic processes.

Appendix G

OLS College Graduation

Table G1

OLS Regressions: Exposed Group and Control Group I

	(1)
VARIABLES	College Graduation
Exposed	-0.0697***
	(0.0101)
Maternal Education	0.0395***
	(0.000385)
Maternal Education x Exposure	0.00577***
	(0.000872)
Constant	-0.0410***
	(0.00432)
Observations	108,183
R-squared	0.114

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

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