Sex matters: the effects of maternal stress during pregnancy*

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Abstract

The purpose of this article is to examine the impact of a negative shock during pregnancy and whether it affects boys and girls differently throughout their lives. It's crucial to study a group of children over time because the initial advantage boys have at birth compared to girls might create a false impression that girls are less susceptible to adverse events during pregnancy. Understanding how the prenatal environment influences child development and the differences in this process between boys and girls can help in formulating policies to address poverty and inequalities. There is a trade-off between viability and vulnerability in fetal programming concerning boys and girls. The research investigates the impact on birth measurements, socio-emotional, cognitive, and psychomotor development, and children's physical and mental health. An external event capable of inducing stress in pregnant women is used to define exposure to stress. On February 27, 2010, Chile experienced one of the most powerful earthquakes in world history. A group of children who were in the womb at the time of the earthquake was compared with a group who were between one day and nine months old. A comprehensive longitudinal database produced by the Early Childhood Research (ELPI) conducted in Chile is utilized. This database enables the tracking of a representative sample of children from all over Chile, with developmental assessments in two time periods, in addition to birth measurements. The study follows children born between 2006 and 2017. The initial results focus on the impact on birth measurements, birth weight, birth size, gestation time in weeks, birth weight to gestation time ratio, and birth size to gestation time ratio. The findings corroborate previous evidence that maternal stress during pregnancy, particularly in the first two trimesters, is a risk factor for the full development of the fetus. It's important to note that the effects found are stronger for boys than for girls. The subsequent set of results pertains to the effect of maternal stress throughout the life cycle, where the effects, especially in terms of socio-emotional skills, appear to be more pronounced for girls, leading to behavioral and mental health issues. This study discusses the gender-specific effects of a negative shock during pregnancy, specifically maternal stress. The discussion contributes to the literature on the origins of inequalities, with a focus on gender inequality. It underscores the importance of analyzing pregnancy shocks while considering the differential impact on boys and girls, as disregarding gender differences may result in undetected effects when both sexes are analyzed together.

Key words: gender inequality, fetal programming, maternal stress, child development

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1 Introduction

Investing in early childhood development has been proven to be an effective strategy for reducing poverty and inequality. Public policies aimed at improving the lives of children and the environments in which they grow up show high rates of return in both developed and developing countries. Cognitive and socio-emotional skills and the physical and mental health of children in their early years are seen as predictors of academic and professional success, health, and quality of life in adulthood. Investing early in the life cycle extends to the prenatal period, which is considered a critical time in forming the individual, shaping future skills and health trajectories (Almond, 2011). The Fetal Origins Theory, or fetal programming, developed by Barker, emphasizes the importance of the environment during pregnancy and how negative or positive shocks affect fetal development. Maternal nutrition, alcohol, tobacco, and drug consumption, along with the physical and mental health of the mother during pregnancy, are factors identified as detrimental to gestation and have adverse outcomes on the child's development through fetal programming (Stevenson, Lillycrop, & Silver, 2020).

Fetal programming refers to how the conditions of the environment during pregnancy can impact the full development of the fetus (Glover, O'connor, & O'Donnell, 2010), with long-term effects on physical and mental health as well as cognitive development throughout life. It's interesting to note that fetal development differs between boys and girls, including their adaptation to the womb environment. While in the womb, male fetuses prioritize resources for body growth but are less adaptable to environmental changes. In contrast, female fetuses have a more remarkable ability to adapt to unfavorable conditions for full fetal development. One well-known difference is the higher risk faced by boys in terms of neonatal mortality and poorer birth outcomes, such as premature birth and low birth weight, known as the male viability problem in epidemiology and human biology. Girls, with their greater adaptive capacity, have a lower risk of viability issues. Still, they are more vulnerable to less severe complications that become detectable only later in life, particularly concerning behavioral problems and mental health (Sandman, Glynn, & Davis, 2013).

This article explores how adverse shocks during pregnancy affect boys and girls differently throughout their lives. It's essential to study a group of children over time because boys may show more significant impacts at birth compared to girls, leading to the mistaken belief that girls are less vulnerable to adverse events during pregnancy. Understanding this process contributes to understanding the origins of observed inequalities between men and women, particularly in terms of physical health and behavioral issues, which could have implications for educational performance and the labor market. It's crucial to recognize that vulnerable families, particularly those facing socioeconomic challenges, are significantly impacted by higher stress levels during pregnancy. This stress can have detrimental effects on fetal development, potentially leading to future cognitive, non-cognitive, and health development issues in children. Understanding the impact of the pregnancy environment on children's development and identifying any gender-based differences is essential for formulating effective policies to address poverty and inequalities.

Stress is an emotional reaction to pressure, fear, and worries and causes physical and chemical changes in pregnant women. These changes can affect the development of the embryo and fetus. Stress can also weaken the immune system of pregnant women, making them more susceptible to illnesses and pregnancy complications like preeclampsia. Additionally, stress can lead to harmful behaviors during pregnancy, such as increased consumption of alcohol, cigarettes, or drugs, and changes in eating patterns that can result in malnutrition or uncontrolled weight gain. The effects caused by the physiological changes in the mother are called direct effects, while the effects resulting from illnesses, pregnancy complications, or behavioral modifications are called indirect effects. It's important to understand these distinctions to develop effective public policies aimed at reducing the adverse effects of maternal stress on fetal development.

This article examines the impact of maternal stress during pregnancy on the development of boys and girls. It looks at how stress affects key birth measures, socio-emotional, cognitive, and psychomotor development, and children's physical and mental health. The study uses the 2010 earthquake in Chile as an exogenous event to assess stress in pregnant women. It compares a group of children in utero during the earthquake with a group that was one day to nine months old. The study uses data from the Early Childhood Longitudinal Survey (ELPI) conducted in Chile, which tracks a representative sample of children born between 2006 and 2017, with developmental assessments at two points in time and birth measures.

The link between earthquakes and post-traumatic stress disorder (PTSD) has been the focus of numerous studies. Earthquakes, as unpredictable natural events, can be devastating for affected populations. Farooqui et al. (2017) state earthquakes are considered the most terrifying and uncontrollable natural disasters. In addition to the visible consequences, such as the destruction of infrastructure, studies have shown that those affected often experience health problems, with PTSD being the most commonly reported issue (Neria, Nandi, & Galea, 2008; Carr et al., 1995; Liu et al., 2006; Başoğlu, Kiliç, Şalcioğlu, & Livanou, 2004; Önder, Tural, Aker, Kılıç, & Erdoğan, 2006; Van Griensven et al., 2006; Dai et al., 2016). The unpredictability of earthquakes and their impact on the incidence of PTSD provide an opportunity to study the effects of stress. Some studies have focused on the relationship between the stress caused by earthquakes in pregnant women and its consequences for the baby's development. For example, torche2012prenatal studied an earthquake that occurred in Chile in 2005 and found that exposure to the earthquake increased the likelihood of premature birth for girls. Guo, He, Song, and Zheng (2019) analyzed the effects of a strong earthquake that occurred in China in 1976 and found that the cohort affected during gestation had a higher risk of developing schizophrenia in adulthood. Noghanibehambari (2022) linked exposure to earthquakes during the prenatal period to life expectancy, finding a reduction in this measure for the exposed cohort.

To understand how maternal stress during pregnancy affects child development, we need to address several challenges. The first challenge is getting accurate information about mothers' stress levels and considering the potential impact of stress. Simply comparing mothers who experienced stress during pregnancy with those who did not may lead to a biased result. Mothers who are more likely to experience stress may have genetic or social characteristics that can also affect child development, which could confound the true impact of stress. This article takes an approach that uses the Chilean earthquake as an example of an external event with a high capacity to induce stress. This earthquake, one of the five strongest ever recorded, caused post-traumatic stress in about 30% of the population in the affected areas, according to subsequent studies.

The second challenge arises when evaluating the effect of prenatal stress on child development measures after birth. It is essential to differentiate between the effects during pregnancy and any potential post-birth effects. A strategy based on Persson et al. (2018) is utilized to address this challenge. The approach involves comparing children in utero at the time of the earthquake with children between zero and nine months old. This allows for comparing children of different ages, as the affected children are, on average, nine months younger than the children in the control group. To prevent the results from being influenced by this age difference, the evaluation measures are standardized for each age of the children at the time they were assessed. This helps to determine whether the affected children are, on average, in a lower or higher position in the distribution for each development measure.

The third challenge relates to the potential endogeneity of the birth date. It is necessary to determine whether the child was in utero during the earthquake. The estimation follows an instrumental variables strategy, where the hypothetical gestation period from the conception date is used as an instrument to correct for this potential endogeneity.

Finally, the last challenge is to isolate the direct effect of stress from the indirect effects. It's not possible to fully isolate the direct effect from the indirect effect with observational data; however, tests can be conducted to compare whether the health status and behavior of mothers during pregnancy differ between the two groups, enabling a better understanding of which effect has more influence on the results obtained.

The article's findings suggest that there is a tradeoff between viability and vulnerability for boys and girls when it comes to the adverse effects of maternal stress during pregnancy. Although both boys and girls are affected by maternal stress, the results indicate that boys are more sensitive to it. Boys experience a more significant impact on birth weight and size than girls; this impact is more important and lasts for a longer gestational period. While the implications for girls is only observed during the second trimester, it is observed in both the first and second trimesters for boys. Furthermore, a crucial measure, the birth weight to gestational age ratio, which indicates fetal growth restriction, shows a negative result only for boys.

For postnatal development measures that indicate vulnerability, the results show that girls are more sensitive, especially in terms of socio-emotional skills and the likelihood of developing mental illness. In the 2 to 3-year-old age group, girls who experienced stress during pregnancy showed more socio-emotional problems compared to girls in the control group. It is essential to note the negative results in measures related to anxiety and depression. No evidence of effects in boys was found for these measures, which is consistent with epidemiological and human biology literature findings.

In the 8 to 9-year-old age group, the results for socio-emotional measures continue to show poorer outcomes for girls, although less significantly than in the previous age group. Girls also exhibited worse results in cognitive ability measures. In terms of health conditions, there is an increase in the likelihood of boys presenting symptoms of asthma and an increase in the probability of both boys and girls manifesting Attention Deficit Hyperactivity Disorder (ADHD) problems, with a greater magnitude of the result for girls.

This paper contributes to the literature by discussing the gender-dependent effects of adverse shocks during pregnancy, specifically maternal stress. It extends the discussion to other dimensions beyond the field of health. It emphasizes the importance of analyzing pregnancy shocks considering the unequal effect on boys and girls. Disregarding gender dependence may result in undetected effects when both sexes are analyzed together.

The third contribution includes a discussion of the gender dependence of the effects of prenatal stress. The biology and epidemiology literature suggests a greater sensitivity of boys to fetal growth compared to girls. However, this lesser sensitivity of girls leads to more significant problems later in life, especially in mental health issues.

To ensure the robustness of the results, several tests were conducted—the first test aimed to confirm the presence of alternative transmission channels. The earthquake, while capable of causing stress in pregnant women, can also lead to material damage, which can affect fetal development. Although it is not possible to rule out all potential alternative channels, the data in the database allows for an assessment of differences between the affected group and the control group in terms of the number of prenatal consultations and the type of delivery, providing insight into changes in access to health services. The results show no impact of the earthquake on access to healthcare, thus reducing the possibility of alternative channels. Therefore, stress is considered the primary transmission channel for the adverse effects observed on child development.

Another crucial point is to determine whether the effect of stress was manifested directly or indirectly. The impact of stress on the physical health of pregnant women and certain behaviors detrimental to pregnancy were examined. The results indicate minor changes in the mother's health, particularly an increased likelihood of the pregnant woman developing a urinary tract infection.

However, this result is only evident for girls' mothers in the third trimester of pregnancy. Since most effects are observed when stress occurs in the second trimester of pregnancy, this outcome cannot significantly influence the main results of the article. Regarding changes in the mothers' behavior, one result that may impact the main findings is a perceived increase in alcohol consumption, which was reported by mothers in the second trimester of pregnancy, the period found to be most sensitive to the negative impact. Nevertheless, the increase in consumption was noted for mothers who reported minimal alcohol intake during pregnancy. Nonetheless, it is impossible to assert that there was no influence from an indirect effect of stress.

Finally, an important assumption to ensure the accuracy of the post-birth measurements is that the events following the earthquake were consistent for both groups of children analyzed. An important issue raised by the literature in this context is the mental health of mothers, both after childbirth and later in the child's life cycle. With the available information, it was confirmed that, overall, the mental health of the mothers in the periods after birth who were pregnant at the time of the earthquake was better than that of the mothers in the control group. Therefore, the post-earthquake events either had no impact on the findings or served to mitigate them, suggesting that the effect of maternal stress may be more substantial than reported in this article.

2 Theoretical Framework

2.1 Fetal programming

The fetal programming hypothesis suggests that adverse events during embryonic and fetal development can lead to permanent changes in organs and metabolism, with long-term consequences such as an increased risk of diseases and developmental problems (Guest, Martins-de Souza, Rahmoune, Bahn, & Guest, 2013; Zhu, Cao, & Li, 2019). Initially proposed by Barker in 1990, this hypothesis aimed to explain the link between maternal nutritional issues during pregnancy and the offspring's risk of cardiovascular diseases in adulthood. Subsequently, other factors such as obesity, alcohol consumption, smoking, drugs, and maternal mental health have been identified as detrimental to fetal development (Stevenson et al., 2020).

Although the biological mechanisms involved in fetal programming are not fully understood, epigenetics plays a significant role in this process (Stevenson et al., 2020; Waterland & Michels, 2007). Epigenetics refers to changes in gene expression without altering the DNA sequence and is a field of biology that studies the interactions between genes and the environment in the production of the phenotype[1].

Fetal programming refers to the plasticity of the human phenotype, which is partially shaped during the intrauterine period. These changes are recorded in the phenotype, thus carrying the adversities faced in the womb into the postnatal period, leading to developmental problems and increased risk of disease.

From Barker's studies, a new field of research emerged with significant contributions to understanding non-communicable chronic diseases. The recognition of the influence of the environment on the development of diseases previously thought to be entirely genetic has facilitated the formulation of public policies that focus on pregnant women and the early years of life to prevent health problems in adulthood. Although the main focus of the literature on fetal programming is related to increased adult disease, there is also interest in understanding how the environment during pregnancy affects individual development in other dimensions, such as behavioral problems, academic and cognitive performance, and mental health.

[1] Phenotype = genotype + environment.

Given the relationship of fetal programming to human development in almost all its dimensions, the economic literature shows a growing interest in the subject. Almond and Currie (2011) e Almond, Currie, and Duque (2018) review the literature, with the first article providing a more theoretical discussion and the second presenting the main empirical articles published in recent years. Almond et al. (2018) highlight the increase in the number of publications that occurred at the beginning of this century. According to (Almond & Currie, 2011), the economic literature contributes to the fetal programming literature in three ways: i) analysis of various other adverse situations besides maternal malnutrition, such as physical and mental illnesses, pollution, climate change, alcohol, and smoking consumption; ii) investigation of other unfavorable outcomes besides physical health in adulthood, such as behavioral and mental health problems, academic, cognitive, and labor market performance; iii) more convincing empirical evidence, with strategies that allow causal inference compared to epidemiological studies, which mainly present only correlations.

2.2 Gender dependence

The empirical literature has not thoroughly explored gender dependence in the context of fetal programming, especially in the economic literature. However, it is crucial to consider this factor because ignoring gender dependence in empirical analysis can obscure results due to different responses between male and female babies.

According to (Sandman et al., 2013; Hicks, Swales, Garcia, Driver, & Davis, 2019), there is a gender dependency in the tradeoff between viability and vulnerability. Adverse effects early in life can affect the viability of boys, increasing the likelihood of mortality and poor birth outcomes. In contrast, these same effects can increase the likelihood of postnatal developmental problems for girls, especially in terms of behavioral and mental health issues.

Differences in embryonic and fetal developmental processes between boys and girls suggest that adverse conditions during pregnancy have different effects on fetal programming (Rosenfeld, 2015; Gabory, Roseboom, Moore, Moore, & Junien, 2013). The placenta plays a crucial role in mediating interaction with environmental events and exhibits sex-specific differences in response to external stresses (Sutherland & Brunwasser, 2018). Carpenter, Grecian, and Reynolds (2017) provide evidence that the placenta in girls has a lower capacity to block the passage of cortisol the mother releases during periods of stress. Another difference between boys and girls is the increased reactivity of the HPA axis in girls, raising the risk of mental health problems, particularly anxiety and depression.

2.3 Gestational period

The time during pregnancy when a stressful event occurs is crucial in understanding the impact of maternal stress on the offspring. Research suggests that pregnancy's early and middle stages, particularly the first and second trimesters, are the most sensitive periods. The increased sensitivity during these stages is due to both the maternal response to stress, which decreases as pregnancy progresses, and the developmental processes during these stages.

Maternal cortisol levels gradually increase during pregnancy. An enzyme in the placenta regulates fetal exposure to maternal cortisol. The levels of this enzyme increase throughout pregnancy, acting as a protective barrier for the fetus against maternal cortisol during critical periods of fetal development. In the later stages of pregnancy, higher cortisol levels are essential for the fetus, particularly for lung development and preventing premature birth. To allow fetal cortisol levels to increase, placental enzyme levels decrease towards the end of pregnancy. This dual process ensures that the fetus is exposed to appropriate cortisol levels throughout development. However, the enzyme does not entirely block the passage of cortisol, and increases in maternal cortisol due to stress are transmitted to the fetus. If this increase occurs during the first or second trimester, a period of significant organ and brain development, the risk of stress-related problems in the offspring increases (Davis & Sandman, 2010)..

Another critical factor is the maternal response to a stressful event, which varies depending on the stage of pregnancy. A study by (Glynn, Wadhwa, Dunkel-Schetter, Chicz-DeMet, & Sandman, 2001) examined the effect of a 1994 earthquake in California, USA, on the emotional response of pregnant women and recent mothers to stress and the duration of pregnancy. The results indicate a decreasing relationship in stress response, meaning that women in their first trimester had the highest stress response, which progressively decreased in the second trimester and was lowest in the third trimester. Interestingly, mothers who gave birth up to six weeks before the earthquake had stress response levels similar to those in the first trimester.

The combination of increased fetal sensitivity and maternal stress response indicates that early and mid-pregnancy are the most critical periods for exposure to prenatal stress. Some research also suggests that the first and second trimesters are particularly sensitive. Davis and Sandman (2010) studied the impact of stress during pregnancy on cognitive and neuromotor development, indicating that high cortisol levels early in pregnancy negatively affect a child's cognitive development, while exposure to high levels late in pregnancy is linked to better performance in mental development tasks. Moreover, (Glynn et al., 2001) found that women in their first trimester during a stress event had the shortest pregnancies, followed by those in their second trimester and then those in their third trimester. They also found that mothers who had given birth previously had the most prolonged pregnancies. Other studies have shown that elevated cortisol levels in the second and early third trimesters increase the likelihood of preterm birth and that mothers exposed to adverse events during the second trimester are more likely to have low birth weight babies and babies who are more petite for their gestational age (Holzman, Jetton, Siler-Khodr, Fisher, & Rip, 2001; Wadhwa, Porto, Garite, Chicz-DeMet, & Sandman, 1998; Khashan et al., 2008).

2.4 Prenatal stress

During pregnancy, the mental health of the mother is a significant factor that can affect the development of children through fetal programming. Although pregnancy is a joyful time for the mother and her family, it can also bring about worry and changes in family dynamics. Various events such as financial problems, relationship difficulties, family responsibilities, employment issues, and concerns about the pregnancy can increase the likelihood of stress during pregnancy.(Dunkel Schetter, 2011; Thompson, 2014; Coussons-Read, 2013).

A growing body of literature, primarily in epidemiology, provides evidence of the negative relationship between stress during pregnancy and the proper development of the pregnancy, with consequences for the mother's health and, in particular, for the development of the fetus (Davis & Sandman, 2010; Coussons-Read, 2013; Dunkel Schetter, 2011; Thompson, 2014; DiPietro, 2012; King, Dancause, Turcotte-Tremblay, Veru, & Laplante, 2012; Huizink, Mulder, & Buitelaar, 2004). Epigenetics has been identified as the primary mechanism explaining the long-term effects of prenatal stress exposure (Cao-Lei et al., 2017).

Stress is understood as a reaction to situations of demand, external pressure, situations of fear, and worries, which make the individual feel incapable of adapting to the imposed situation, thus altering their emotional state. According to DiPietro (2012), there are no neural connections between the pregnant woman and the fetus; therefore, the mother's emotional state must manifest itself physiological changes to affect the fetus. Stress triggers a series of physical and chemical changes in the pregnant woman. Stress triggers a reaction in the HPA axis, releasing elevated levels of cortisol Cao-Lei et al. (2020), and specifically in pregnant women, it alters blood flow to the uterus.

In addition to changes in cortisol levels and blood flow to the uterus, stress also impairs the immune and inflammatory systems of the pregnant woman, increasing the risk of diseases and complications during pregnancy (Cohen et al., 2007; Padgett and Glaser, 2003). Another adverse reaction to stress in pregnant women is the increased likelihood of risk behaviors during pregnancy, such as smoking, drug, and alcohol use, as well as changes in eating habits. Therefore, maternal stress can negatively affect fetal development directly through physiological changes in the mother's body or indirectly through stress-related health problems and changes in the mother's behavior.

The main interest in the literature is to understand the mechanisms and consequences of the direct effect. How physiological changes in the mother's body are transmitted to the children and what the consequences are for the children's development. Although these mechanisms are not fully understood, it is known that the main response in the pregnant woman's body is the alteration of cortisol levels with dysregulation of the hypothalamic-pituitary-adrenal (HPA) axis (Cao-Lei et al., 2020). These changes in the pregnant woman cause a response in the fetus's HPA axis that is responsible for behavioral and mental problems in childhood and adulthood.

In order to better comprehend the impact on the child, it is important to identify the specific period during the pregnancy when the mother experiences stress, as well as the sex of the baby. Studies have shown that maternal stress during early and mid-pregnancy can have more detrimental effects on the fetus, and the type of developmental issues depends on the stage of fetal development..

3 Data and Variables

The primary data source used in this article is the Longitudinal Survey of Early Childhood (Encuesta Longitudinal de la Primera Infancia - ELPI), conducted in Chile since 2010. The main objective of the ELPI is to monitor early childhood development in Chile and to study the process of child development. The survey is representative of the entire Chilean territory for children born between January 1, 2006, and December 31, 2016. The sample is representative for each month of birth within this period. This is critical to the identification strategy used in the article, as it allows for comparisons between groups of children who were in the womb during the earthquake and children who were born just before the earthquake.

So far, three interviews have been conducted: the first in 2010, the second in 2012, and the third in 2017. In each round, selected households receive two visits. The first visit involves administering a questionnaire to gather socioeconomic and demographic information about the household. During the second visit, instruments are used to assess the children's cognitive, socioemotional, and physical development and their primary caregivers (Contreras & González, 2015). The features of this database make it possible to assess development on multiple dimensions at three points: birth, age two to three, and age seven to eight.

In addition to ELPI, the National Socioeconomic Characterization Survey of Chile (CASEN) (CASEN, 2009) is used. CASEN is a survey conducted by the Chilean Ministry of Social Development since 1990, with a frequency that varies between biennial and triennial. The survey's objective is to investigate the conditions of the population and their households, including demographic, educational, health, housing, employment, and income aspects. It is a national survey with representativeness for all regions of Chile [2]. This work uses

[2] Discussion on the geographic division of Chile

data from the 2009 survey to characterize the affected areas with pre-earthquake information.

3.1 Child Development Measures

The study conducted in Chile allows for tracking children's development over time and across different developmental dimensions. Specifically, for the sample of children used in this article, who were born between June 2009 and December 2010, it is possible to assess the children at three different points in time. The first assessment takes place right after birth, allowing for the analysis of the initial effects of maternal stress. Although these measures are commonly evaluated in the literature, it is essential to assess them in this article for two reasons. First, because few articles with an empirical strategy capable of inferring causality have separately analyzed the effects on boys and girls and have not investigated the impact on Apgar scores; and second, to compare the results with those already found in the literature and to demonstrate the robustness of the method used in this article.

Two more points in time are analyzed after birth. The first is when the children are between 2 and 3 years old. At this stage of the life cycle, the ELPI assessments make it possible to assess the children's emotional, behavioral, and cognitive development. The second post-birth period analyzed is for children between the ages of 7 and 9, where, in addition to the two dimensions evaluated in the previous stage of the life cycle, the physical and mental health of the children is analyzed.

Birth measures are the most studied in the literature on fetal programming. The most studied are birth weight and gestational age. The database used in this article makes it possible to study the effect of maternal stress on these two classic measures and analyze the impact on birth size and 1- and 5-minute Apgar scores. The Apgar test aims to assess the vitality of the newborn. It is widely used because of its reliability and ease of application, becoming the most commonly used measure for immediate assessment of the baby. The test scores five signs: muscle tone, heart rate, reflexes, skin color, and breathing. Each sign is assigned a score from zero to two, so the Apgar score ranges from zero to ten. Scores below seven indicate perinatal asphyxia. The test is performed at the first minute of life and the fifth minute. The first-minute score is related to the pH of the umbilical cord and indicates possible intrapartum asphyxia. A low score on this first test requires immediate medical attention but does not indicate future health problems for the baby if there is an improvement on the five-minute test. The five-minute test indicates possible neurological problems if the score is less than five.

Both birth weight and birth size are essential measures and are correlated with future health problems, especially metabolic problems. However, these measures may indicate that the baby was born prematurely and has not yet reached ideal weight and size or suffered from intrauterine growth restriction and was born at the right time but was smaller. Therefore, two additional measures have been created that give a better idea of fetal development: birth weight for gestational age and birth size for gestational age. Gestational age is expressed in weeks and was obtained through a questionnaire administered to the mothers.

The Test of Learning and Infant Development (TADI) is designed for children between 2 and 3 years of age. It was developed in Chile in 2012 and is specifically tailored to Chilean culture, eliminating the need to adapt tests from other cultures. The TADI assesses development and learning in four dimensions: cognitive, motor, language, and socio-emotional. Each dimension has its own scale, and when combined, they provide an overall indicator of development. The TADI is administered individually to each child and requires the presence of a responsible adult and the child.

In 2017, ELPI administered two tests to assess the cognitive development of 7- and 8-year-old children: the Woodcock-Muñoz III Battery (WM) and the Peabody Picture Vocabulary Test (PPVT). The WM is a

Spanish adaptation of the Woodcock-Johnson test, used to assess development in areas such as computation, mathematical fluency, and applied problems. The PPVT is a Spanish adaptation of the Peabody Picture Vocabulary Test, designed to measure vocabulary acquisition and the child's verbal ability.

The Child Behavior Checklist (CBCL) was used to assess socio-emotional skill development in both 2- and 3-year-olds and 7- and 8-year-olds. Developed by Achenbach and Rescorla in 2001, the CBCL evaluates children's behavior and socio-emotional skills based on information reported by parents. Childhood behavior problems can be indicative of adult psychopathology and are categorized into two major groups: internalizing and externalizing problems. Internalizing problems include emotional reactivity, anxiety/depression, and somatic complaints while externalizing problems refer to aggressive and rule-breaking behavior.

The study examined the effects of maternal stress on the physical and mental health of children aged 8 and 9. The database contains questions in which mothers report whether their children have asthma, attention deficit hyperactivity disorder (ADHD), anxiety, food allergies, or any developmental disorders.

3.2 Standardization of development measures

As described in the next section, the empirical strategy adopted in this article is based on comparing children who were in the womb at the time of the earthquake and children who were born nine months before the earthquake. Due to this strategy, the treatment group is by construction composed of younger children than those in the control group. Although the age difference is not very large and would not interfere with comparing these two groups in adulthood, the comparison in this article is made with children two to three years old and seven to eight years old.

To ensure that the results found in the estimates were not influenced by the age of the child, standardization of all developmental measures was performed by the age of the child in months. This standardization consists of normalizing the results for children who were the same age, measured in months of life, at the time they were assessed.

The standardization was performed on all children in the sample, while the estimations were performed only on children born in the earthquake-affected areas. Therefore, the results presented in the article indicate whether the children who experienced the shock during pregnancy are in different positions within the distribution of each analyzed dimension.

4 Empirical strategy

4.1 Identification

The main focus of this article is to estimate the impact of maternal stress during pregnancy on child development. Specifically, the goal is to estimate the biological effects that stress experienced by the mother during pregnancy may have on fetal formation and subsequent child development. To achieve this goal, it is important to address four main challenges: 1) the difficulty of measuring stress; 2) differentiating in utero effects from potential postnatal effects; 3) isolating the biological effects of stress from other stress-related issues; and 4) the endogeneity of birth date.

The main challenge is the difficulty in obtaining information on the stress levels experienced by pregnant mothers, and the potential issue of stress being linked to other factors. Families facing socioeconomic challenges are more likely to experience stress, especially pregnant women. The primary method of measuring stress is through cortisol laboratory tests, but databases with this information are rare and have few observations. Furthermore, these databases would need to be compared with data on child development. While there are studies with this type of information, they are correlational due to the nature of the data collection, and therefore have limited validity for causal analysis.

The 2010 earthquake in Chile is used as an example of stress. The earthquake is an external event that has the potential to cause post-traumatic stress in affected individuals. This natural experiment induces stress by comparing the development of children in utero in the affected areas at the time of the earthquake with the development of children born shortly before the earthquake.

The earthquake referenced occurred on February 27, 2010, with a magnitude of 8.8 on the Richter scale. This earthquake caused tremors in the coastal regions of Chile, where around 80% of the population resides. It is considered one of the five largest earthquakes ever recorded in history. In addition to the Richter scale, the Mercalli scale can also be used to measure earthquake intensity. The Mercalli scale evaluates the effects of the earthquake on people, natural objects, and human structures, providing a more accurate assessment of the induced stress. The scale consists of twelve levels: imperceptible (I), very weak (II), weak (III), moderate (IV), strong (V), very strong (VI), severe (VII), damaging (VIII), destructive (IX), very destructive (X), devastating (XI), and catastrophic (XII). Intensity information for each province of Chile was obtained from the United States Geological Survey (USGS) website, showing a range of intensities from very weak (II) to damaging (VIII).

The child's date of conception was used to determine whether the mother was pregnant at the time of the earthquake. Children conceived before the earthquake and not born by the date of the earthquake were considered in the treatment group, and children born one day to nine months before the earthquake were considered in the control group. Evidence suggests that the timing of gestational shock influences fetal and later child development. Therefore, in addition to defining the treatment group as described above, a specification with three treatment groups was also made, one for each trimester of pregnancy.

Analyzing the impact of a prenatal shock on future outcomes presents the challenge of distinguishing between the effects during fetal development and potential postnatal effects. Almond and Currie (2011) propose comparing a group of individuals who were in utero at the time of the shock with a group born immediately before or conceived shortly after the shock as the main strategy to address this issue.

When assessing the impact of post-traumatic stress during pregnancy, it is not recommended to use children conceived after the stressful event as a control group. This is because there is evidence that the effects of post-traumatic stress may appear some time after the event, contaminating the control group. In the case of using the Chilean earthquake as a shock event, children conceived after the earthquake may have had access to better health infrastructure during their pregnancies due to the rapid and efficient reconstruction efforts undertaken by the Chilean government. Consequently, this group of children may show better outcomes in developmental measures, not because of the negative effect of stress, but due to the positive effect of improved living conditions.

This article addresses the challenge by comparing children who were in the womb at the time of the earthquake and whose mothers lived in the affected areas, with children who were one day to nine months old and also lived in the affected areas. The analysis assumes that the decision to become pregnant is not influenced by the unpredictability of an earthquake.

The third challenge results from the strategy adopted to address the first challenge. In addition to inducing post-traumatic stress, the earthquake may affect mothers in other ways beyond stress, such as economic changes, access to public and health services, physical health, and behavioral changes. It is not possible to completely isolate these possible effects from the effect of stress. However, Chile has one of the world's most effective disaster preparedness infrastructures. Despite the intensity of the earthquake and the destruction in some parts of the country, the reconstruction process and the urban interventions carried out by the Chilean government were so efficient that some areas affected by the earthquake showed improvements in quality of life indicators after reconstruction. In addition, a series of estimations are carried out to check the plausibility of the main estimates that capture the impact of stress. The database used includes information on maternal health during pregnancy and some behaviors that may affect fetal development, such as smoking, drinking, and drug use. In a section on transmission mechanism analysis, comparisons are made between the treatment and control groups to check for possible differences between the groups.

The fourth challenge is related to the problem of endogeneity of the date of birth. This problem arises in two ways. Longer gestations are more likely to be affected by a shock, and since babies born after longer gestations tend to be healthier, this endogeneity can lead to an underestimation of the results. Conversely, the negative shock itself may induce shorter gestations, creating a correlation between gestation and shock. The solution adopted in the literature is to use an instrument with the theoretical gestation period from the date of conception.

The causal effect of maternal stress during pregnancy is determined by assuming that the earthquake is independent of the decision to become pregnant and the timing of the earthquake.

4.2 Specification

Two specifications are used: one to estimate the effect of stress during pregnancy and another to analyze if the gestational timing of the shock has different impacts. For both specifications, an estimation with instrumental variables is conducted.

In the first specification, the objective is to globally evaluate the impact of stress during pregnancy. It is important to conduct this specification because some effects may not appear significant due to the sample size when looking at the division by trimesters. The first stage of this specification is an estimation where the dependent variable is a binary variable indicating whether the child was in the womb at the time of the earthquake, instrumented by a variable that indicates the theoretical pregnancy time counted from the estimated date of conception[3].

$$utero_i = \gamma instrument_i + X_i\tilde{\beta} + \tilde{\theta_r} + \mu_i \tag{1}$$

The second stage estimates the effect of maternal stress during pregnancy on a series of child development measures discussed in the previous section (Data and Variables).

$$y_i = \alpha \hat{utero}_i + X_i\beta + \theta_r + \epsilon_i \tag{2}$$

In this context, y_i represents the various development measures, *utero* indicates that the child was in the womb at the time of the earthquake, and X is a vector of covariates. These covariates include the mother's age at childbirth, the presence of siblings, whether the mother belongs to an Indigenous community, the total number of household residents, the mother's marital status, the presence of a television in the household, and variables indicating the employment and health conditions of the residential regions prior to the earthquake.

The second specification aims to analyze whether the timing of the shock during pregnancy impacts the outcomes differently. In this specification, the potential endogeneity of the birth date is reflected in the variable indicating the third trimester of pregnancy. Therefore, the first stage of this specification is an

[3]The conception date was estimated using the birth date minus the gestational period

estimation where the dependent variable is the indicator of the third trimester, with the instrument being a hypothetical measure of the duration of the third trimester of a standard pregnancy.

$$trimester_3 = \gamma instrument + \tilde{\alpha_1} trimester_1 + \tilde{\alpha_2} trimester_2 + X_i \tilde{\beta} + \theta_r + \mu_i \quad (3)$$

The second stage estimates the effect of maternal stress separately for each trimester of pregnancy.

$$y_i = \alpha_1 trimester_1 + \alpha_2 trimester_2 + \alpha_2 trim\hat{e}ster_3 + X_i \beta + \theta_r + \epsilon_i \quad (4)$$

For each of the specifications, three estimations were conducted. The first one is for the entire sample of children, and the other two are to analyze the effect separately for boys and girls.

5 Results

This section presents the results of the article. The first subsection presents the impact of the earthquake during gestation on birth measures, socio-emotional development, overall and psychomotor development, and physical and mental health conditions. For socioemotional development and overall and psychomotor development, the results are presented for two age groups, 2 and 3 years old and 7 and 8 years old, while for health conditions, they are presented only for the older age. The results are presented chronologically to facilitate tracking the effects throughout the life cycle.

All results tables have three panels. Panel A presents the results for the entire sample, including both boys and girls. Panel B presents the results for the estimates for boys only, while Panel C is for girls only. Each panel has two estimates. The first shows the effect of maternal stress during pregnancy regardless of the trimester, while the second estimation tries to determine which trimester is more sensitive.

Some results are then presented to test the existence of possible alternative transmission channels, to verify the presence of indirect effects of stress, and to check whether postnatal conditions influenced the results.

5.1 Main results

This subsection presents the results of the impact of stress during gestation on child development throughout the life cycle. The first set of results pertains to the impact on birth measures, including birth weight, birth length, gestational age in weeks, birth weight to gestational age ratio, and birth length to gestational age ratio. Birth measures are the most studied outcomes in the literature on the effects of maternal stress, especially birth weight and gestational age, with evidence indicating a negative effect on these measures, particularly for male children. The early and middle stages of gestation are identified as the most sensitive periods (King et al., 2012).

The results presented in Table 1 support the evidence already indicated in the literature: maternal stress during pregnancy, especially in the first two trimesters, is a risk factor for full fetal development. The problems associated with maternal stress manifest themselves shortly after birth, either in reduced gestational age or in lower birth weight and length measures. Notably, the effects are stronger in boys, both in terms of statistical significance and magnitude.

It is important to emphasize that, unlike the postnatal measures, the estimate obtained for the birth measures is a pure effect of maternal stress during pregnancy since the control group was not affected by the shock. For the other measures analyzed below, the effect found is the difference between experiencing the shock in the womb and experiencing the shock in the first months of life.

Panel A of Table 1 shows the results for the entire sample analyzed without distinguishing the baby's sex. It is noticeable that birth weight was the measure most affected by maternal stress. In the first estimation, the effect of stress during pregnancy indicates a reduction of 97 grams in the baby's birth weight. The negative result is a well-established finding in the literature, but the magnitude of the effect varies, both due to different empirical strategies and to the stressor used. Considering studies from the economic literature that use empirical strategy that allow for causal inference, (Aizer, 2011), who analyzed the effect of domestic violence, found a reduction of 187 grams, while (Persson & Rossin-Slater, 2018), who analyzed the effect of the death of a close relative, found a reduction of 18 grams.

Regarding birth weight, the second column of the table shows that maternal stress increases the probability of having a low birth weight baby (less than 2,500 grams) by just over 2%. More important than looking at low birth weight is looking at the ratio of birth weight to gestational age. The reduction in birth weight may indicate that the child was born prematurely or experienced growth restriction during pregnancy, which may be a better indicator of future problems. The result suggests a reduction in this ratio, which means that maternal stress caused fetal growth restriction, suggesting that other developmental issues may have occurred and may manifest throughout the life cycle. The different results do not show statistical significance when gestational age is analyzed aggregately.

A second estimation reported in Panel A shows the difference in effect depending on the gestational period in which the stressful event occurred. The result confirms other evidence from the literature that the first two trimesters of pregnancy are the most sensitive, with the second trimester showing slightly greater sensitivity in terms of effect size. The birth weight estimate showed negative effects in both the first and second trimesters, as did the birth weight for gestational age ratio. The first two trimesters showed significant results for both measures, although the magnitude was greater for the second trimester. Contrary to the aggregate estimate, when the effect was analyzed separately by trimester, no effect was found on the probability of being born with a low birth weight. However, a small effect on birth size was found for children who were in the first trimester of fetal development at the time of the earthquake.

Analyzing boys and girls together provides only a partial view of the problem. It's crucial to look at them separately because fetal development is different for each sex, as is the effect of adverse shocks. Panels B and C show separate results for boys and girls. It's worth noting that boys are more sensitive to maternal stress. Girls are affected only in terms of birth weight and height, with smaller magnitudes and levels of significance. In addition, the effect only manifests itself in the second trimester for girls. For boys, negative effects are observed for both birth weight and size and birth weight for gestational age. Birth weight is the most affected measure. Boys in the second trimester of fetal development at the time of the earthquake were born, on average 194 grams lighter, while those in the first trimester experienced a reduction of 167 grams. In terms of birth size, the first two trimesters are again the most sensitive, with the first trimester showing a more significant effect, resulting in boys being born almost 1 centimeter shorter. The ratio of birth weight to gestational age shows a negative impact on boys in the second trimester of fetal development. However, the effects were weaker and concentrated in the second trimester for girls. Birth weight had a negative impact of 134 grams, while birth length decreased by only half a centimeter.

The results presented in Table 1 corroborate the evidence from the literature regarding the negative relationship between maternal stress and fetal development as measured by birth outcomes. The first two trimesters of pregnancy are highlighted as being the most sensitive, particularly the second, with the effects

Table 1: Birth measurements

	Birthweight	Low birthweight	Size	Gestation time	Weight/time	Size/time
			Panel A - Entire sample			
Pregnancy	-0,0971**	0,0242*	-0,1732	-0,1613	-0,0021**	0,0011
1º Trimester	-0,1309**	0,0082	-0,4998*	-0,2493	-0,0028**	-0,0035
2º Trimester	-0,1506***	0,0254	-0,3400	-0,2141	-0,0033***	0,0018
3º Trimester	-0,0150	0,0383	0,3100	-0,0262	-0,0004	0,0051
Observations	774	774	748	774	774	748
Panel B - Boys						
Pregnancy	-0,1062**	0,0211	-0,3603	-0,0716	-0,0026*	-0,0068
1º Trimester	-0,1672**	0,0136	-0,9375**	-0,3624	-0,0034	-0,0105
2º Trimester	-0,1942***	0,0252	-0,4295*	-0,0379	-0,0048***	-0,0075
3º Trimester	0,0347	0,0230	0,2439	0,1561	0,0004	-0,0024
Observations	388	388	375	388	388	375
Panel C - Girls						
Pregnancy	-0,1041*	0,0335	-0,0518	-0,1908	-0,0022	0,0048
1º Trimester	-0,1065	0,0143	-0,0334	-0,1840	-0,0023	0,0050
2º Trimester	-0,1335*	0,0342	-0,5112*	-0,3927	-0,0024	0,0042
3º Trimester	-0,0747	0,0557	0,3724	-0,0166	-0,0019	0,0050
Observations	386	386	373	386	386	373

being more pronounced in boys. These measures are important because there is evidence that they are related to developmental problems in the later stages of the life cycle. However, these results provide only a partial view of the problem, as they suggest that girls are less affected by maternal stress during pregnancy than boys. The next set of results examines the effect of maternal stress during pregnancy at two other points in the children's life cycle: when they are between 2 and 3 years old and when they are between 8 and 9 years old. These results aim to show that the lower sensitivity of girls in birth measures comes at the expense of more significant problems later in the life cycle, especially in socio-emotional development and mental health pathologies.

Table 2 shows the results for the 2- and 3 years. In this age group, it is possible to assess socio-emotional skills and the child's level of learning and overall development. Non-cognitive development is estimated using the Childhood Behavior Checklist (CBCL). Three aggregate measures of emotional functioning are presented. The internalizing dimension includes problems of emotional reactivity, anxiety/depression, and somatic complaints, while the externalizing dimension refers to conduct problems and rule-breaking behavior. In addition, a combined measure of these two dimensions is provided.

As mentioned in the database section, the raw scores were standardized to the children's age in months to prevent the results from being influenced by the children's age. For this particular measure, standardization was performed separately for boys and girls. The results should be interpreted as deviations from the population distribution in each age group, with higher scores indicating more significant conduct problems. The other assessment used in this age group is the Test of Learning and Child Development (TADI). In addition to providing an overall measure of development, the TADI allows for the assessment of four separate dimensions of development: socio-emotional, language, motor, and cognitive.

The first results presented in table 2 refer to the aggregated measures of non-cognitive development. The results from Panel A, full sample, and Panel B, boys, do not indicate an effect of maternal stress. However, Panel C, results for girls, indicates that girls who were in the second trimester of fetal development at the time of the earthquake had more significant problems related to socio-emotional development. The aggregate and externalizing measures show positive and significant coefficients. Although the internalizing measure does not show a significant coefficient, the table presented in the Appendix, which includes the disaggregated measures, shows an effect associated with increased anxiety and depression problems in girls. The results presented in the tables 2 and the Appendix suggest that despite the lower sensitivity observed in the birth measures for girls, emotional problems can be perceived throughout the life cycle. This finding is consistent with the theory of viability and vulnerability discussed in the human biology literature (Sandman et al., 2013).

Still in table 2, the results for learning and general development show heterogeneous results for boys and girls; both are affected, but at different stages of gestation and in different dimensions of development. Boys showed problems in language and cognitive development, with the first trimester of pregnancy being the most sensitive. For girls, the affected dimension was motor development, particularly for those in the third trimester of pregnancy. This finding is consistent with evidence from the literature that girls are more sensitive in the motor development dimension (?, ?).

Table 2: Second round

	Socioemotional			Learning and Development				
	Total	Internalizing	Externalizing	Total	SE	Language	Motor	Cognitive
Panel A - Entire sample								
Pregnancy	0,1083	0,0923	0,1104	-0,0863	-0,0220	0,0175	-0,0992	-0,1457*
1º Trimester	0,1255	0,1287	0,1414	-0,1333	0,0009	0,0068	-0,1012	-0,2843***
2º Trimester	0,0391	0,0083	0,0896	0,0251	0,0379	0,0894	-0,0435	-0,0322
3º Trimester	0,1499	0,1285	0,0966	-0,1376	-0,0961	-0,0352	-0,1440	-0,1079
Observations	765	765	767	762	767	764	766	766
Panel B - Boys								
Pregnancy	0,0910	0,0873	0,0540	-0,1189	-0,0665	-0,0087	-0,0776	-0,1515
1º Trimester	0,3062	0,2486	0,2771	-0,2791**	-0,1409	-0,2318*	-0,0733	-0,3124*
2º Trimester	-0,1621	-0,1190	-0,1390	0,1217	0,0790	0,2738	-0,0329	0,0327
3º Trimester	0,1332	0,1332	0,0363	-0,1923	-0,1289	-0,0668	-0,1182	-0,1711
Observations	384	384	386	382	385	384	384	384
Panel C - Girls								
Pregnancy	0,1418	0,1139	0,1738*	-0,0509	0,0240	0,0497	-0,1261	-0,1246
1º Trimester	0,0173	0,0517	0,0946	0,0207	0,1648	0,2118	-0,1002	-0,2426
2º Trimester	0,3319*	0,2580	0,3549**	-0,0400	0,0230	-0,0912	-0,0057	-0,0392
3º Trimester	0,1241	0,0607	0,1080	-0,1512	-0,1533	-0,0241	-0,2707**	-0,0548
Observations	381	381	381	380	382	380	382	382

The next stage of the life cycle we are analyzing is the age range of 8 to 9 years. During this stage, we have information about the cognitive and non-cognitive skills, as well as the physical and mental health of the children. In Table 3, you can see the results of the impact of stress on socio-emotional and cognitive skills. The results in Panel A, which are related to socio-emotional skills, indicate an improvement in socio-emotional skills for children who were in the second trimester of fetal development at the time of the earthquake. It's important to note that this finding doesn't mean that being in the womb during the earthquake reduces behavioral problems in children at ages 8 and 9. Rather, it suggests that maternal stress is more likely to affect children who are already born, making the effect of fetal programming less relevant. When comparing the results for boys and girls, we observe that this result is only true for boys. Girls who were in utero still show worse outcomes compared to girls who were already born at the time of the earthquake.

Cognitive skills were measured using the Woodcock-Muñoz test, which assesses academic performance through tests of calculation (cc), mathematical fluency (fd), and applied problems (pa), and the TVIP test, which measures vocabulary acquisition. The last dimension analyzed by the WM test is related to calculation. Once again, the second trimester proves to be the most sensitive period; however, it is not possible to determine a gender difference for this dimension, as both boys and girls are similarly affected.

Table 3: Third round

	Socioemotional			Cognitive skills		
	Total	Internalizing	Externalizing	Apl Prob	Fluidity mat	Calculus
			Panel A - Entire sample			
Pregnancy	0,0071	-0,0174	0,0082	-0,0462	-0,0510	-0,0468
1º Trimester	0,0311	-0,0565	0,0714	-0,0512	0,0210	-0,0043
2º Trimester	-0,2010**	-0,1760**	-0,2066***	-0,1550	-0,1680	-0,2292**
3º Trimester	0,1626	0,1565	0,1320	0,0545	-0,0176	0,0736
Observations	773	773	773	771	770	770
Panel B - Boys						
Pregnancy	-0,0303	-0,0803	-0,0453	-0,0577	0,0069	-0,0477
1º Trimester	0,0832	-0,0712	0,1320	-0,0193	0,1198	-0,0240
2º Trimester	-0,2920***	-0,2978**	-0,2860***	-0,2111	-0,0565	-0,2196
3º Trimester	0,1053	0,1069	0,0177	0,0523	-0,0352	0,0957
Observations	388	388	388	385	384	384
Panel C - Girls						
Pregnancy	0,0548	0,0226	0,1011	-0,0334	-0,1471	-0,0491
1º Trimester	0,0071	-0,0569	0,0638	-0,0516	-0,0306	-0,0097
2º Trimester	-0,0756	0,0016	-0,0984	-0,1463	-0,3857**	-0,2266
3º Trimester	0,2293	0,1390	0,3244*	0,0889	-0,0788	0,0598
Observations	385	385	385	386	386	386

After analyzing the effects of stress during pregnancy on developmental measures, attention turns to the analysis of health problems in children at ages 8 and 9. Table 4 presents the results of estimations of the effects on the probability of the child having asthma, attention-deficit/hyperactivity disorder (ADHD), and language difficulties. For asthma, there is an observed increase in the probability that the child will develop an asthmatic condition. This increase occurs in children who were in their third trimester and is observed only in boys. Similar findings were reported in Lee et al. (2016). The results for ADHD suggest that maternal stress during pregnancy increases the likelihood that the child will manifest this disorder. This association is well documented in the literature, particularly in epidemiologic studies (Ronald, Pennell, & Whitehouse, 2011). However, the differential effect based on the sex of the child has been less studied. The results in the table 4 indicate that both sexes are affected, but at different times and with different intensities. Although the incidence of ADHD is higher in boys, the effect of maternal stress is greater in girls. The impact in boys occurs in the first trimester of pregnancy, with an increase of about 8 percentage points. For girls, the effect occurs in the third trimester, with an increase of almost 13 percentage points. The finding regarding the likelihood of manifesting ADHD supports the initial thesis of the article that although girls are less sensitive at birth, they are more susceptible to developing mental illness and behavioral problems throughout the life cycle.

This subsection summarizes the key findings of the article. The findings support the viability versus vulnerability theory. The study found that boys showed greater vulnerability at birth, while girls were more affected across their life span, especially in terms of behavioral and mental health issues. The subsequent results explore other ways the earthquake could have affected people and the indirect impact of stress. They

Table 4: Health

	Asthma	ADHD	Speech difficulties
	Panel A - Entire sample		
Pregnancy	0,0183	0,0683***	0,0033
1º Trimester	-0,0232	0,0463*	0,0043
2º Trimester	-0,0058	0,0429	-0,0180
3º Trimester	0,0796*	0,1108***	0,0213
Observations	773	769	770
Panel B - Boys			
Pregnancy	0,0508	0,0747**	-0,0296
1º Trimester	-0,0031	0,0862*	-0,0394*
2º Trimester	0,0280	0,0627	-0,0292
3º Trimester	0,1178**	0,0729	-0,0201
Observations	388	386	386
Panel C - Girls			
Pregnancy	-0,0152	0,0445	0,0394**
1º Trimester	-0,0357	0,0095	0,0486
2º Trimester	-0,0478	-0,0039	-0,0041
3º Trimester	0,0387	0,1298**	0,0676*
Observations	385	383	384

also examine the mental health of mothers in the postpartum period.

5.2 Alternative Channels

The results of the previous subsection indicate that children who were in the womb at the time of the earthquake had developmental problems and an increased likelihood of manifesting diseases compared to those who were between one day and nine months old. It was argued that the cause of these problems was maternal stress during pregnancy. However, a direct measure of stress was not used for the reasons explained in the methodology section. By using the earthquake as a stress-inducing event, it is necessary to examine whether it could have caused damage other than stress that could adversely affect the development of children in the womb and, consequently, interfere with the results presented earlier. Among the possible damages caused by the earthquake, the conditions of the health system could be the most important for pregnant women.

To test whether the earthquake affected pregnant women's access to health care, Table 5 presents the results of comparing the number of antenatal visits and the type of delivery among women who were pregnant at the time of the earthquake with those who were pregnant up to nine months before the earthquake. The results did not indicate any change in the type of delivery. Regarding prenatal care, an increase in the number of visits was observed among mothers who were in the second trimester of pregnancy, especially among mothers of girls. Therefore, despite the significant impact of the earthquake, there is no evidence that pregnant women's access to the health system was affected. This suggests that this alternative channel cannot explain the previously presented results.

5.3 Indirect Effects of Stress

The results mentioned above regarding the impact of maternal stress on child development do not clarify whether the effect was a direct result of biological changes in the mother due to stress or an indirect result

Table 5: Alternative Channels

	Prenatal	Type of delivery
	Panel A - Entire sample	
Pregnancy	0,0239	0,0233
1º Trimester	-0,0450	0,0311
2º Trimester	0,1017**	0,0212
3º Trimester	0,0198	0,0171
Observations	759	774
Panel B - Boys		
Pregnancy	-0,0370	0,0240
1º Trimester	-0,1568	0,0857
2º Trimester	0,0307	0,0071
3º Trimester	0,0057	-0,0155
Observations	382	388
Panel C - Girls		
Pregnancy	0,0781	0,0250
1º Trimester	0,0598	-0,0390
2º Trimester	0,1681**	0,0601
3º Trimester	0,0192	0,0691
Observations	377	386

of health issues or behavioral changes in the mother caused by stress. This section aims to determine if the stress experienced by the mother affected her health or behavior during pregnancy.

The ELPI database contains some information about the mother's physical health during pregnancy. It examines the impact on the likelihood of pre-eclampsia, urinary tract infection, hemorrhage, hypertension, placenta previa, diabetes, and anemia. Table 6 shows the results.

Table 6: Mother's health during pregnancy

	Preeclampsia	Urinary infection	Bleeding	Hypertension	Pla previa	Diabetes	Anemia
			Panel A - Entire sample				
Pregnancy	-0,0069	0,0389	0,0202*	-0,0043	0,0201	-0,0014	-0,0504*
1º Trimester	-0,0133	0,0391	0,0129	0,0186	0,0335	-0,0011	-0,0664**
2º Trimester	0,0084	0,0129	0,0383	-0,0096	0,0053	-0,0220	-0,0604
3º Trimester	-0,0141	0,0611	0,0108	-0,0217	0,0197	0,0167	-0,0249
Observations	774	774	774	774	774	774	774
Panel B - Boys							
Pregnancy	-0,0087	0,0187	-0,0038	0,0062	0,0199	-0,0137	-0,0159
1º Trimester	-0,0003	0,0427	-0,0225**	0,0394	0,0336	0,0161	-0,0382
2º Trimester	0,0042	0,0161	0,0233	0,0267	0,0169	-0,0461	-0,0095
3º Trimester	-0,0279**	-0,0007	-0,0126	-0,0426**	0,0098	-0,0089	-0,0017
Observations	388	388	388	388	388	388	388
Panel C - Girls							
Pregnancy	-0,0071	0,0668*	0,0478***	-0,0177	0,0183	-0,0058	-0,1009**
1º Trimester	-0,0267*	0,0321	0,0529**	-0,0062	0,0388	-0,0093	-0,0874
2º Trimester	0,0071	0,0362	0,0534	-0,0311	-0,0175	-0,0070	-0,1386**
3º Trimester	0,0032	0,1356**	0,0366	-0,0192	0,0262	-0,0006	-0,0828
Observations	386	386	386	386	386	386	386

The study did not show any connection between the earthquake and an increase in the likelihood of placenta previa and diabetes. In fact, it revealed that pregnant women at the time of the earthquake were less likely to experience pre-eclampsia, hypertension, and anemia. This suggests that the earthquake may have had no impact on these conditions or may have even lessened their occurrence, resulting in the underestimation of the impact of stress on child development as presented in the previous section.

Further analysis is needed for urinary tract infections and hemorrhages. According to Table 6, there is a higher chance of hemorrhage during pregnancy in women who were pregnant at the time of the earthquake. However, the increased risk of hemorrhage seems to only affect mothers of girls, while the negative effects on low birth weight were observed in both genders, more significantly in boys. Even if this impacts the results, it would not be sufficient to reverse the effects on development due to the low incidence of bleeding in the studied population, which was just over 2% of cases.

The other result that could be a confounding factor in the main results is the increased likelihood of the mother having a urinary tract infection, as can be seen in column 3 of the table 6. Again, however, this increased likelihood is unlikely to have affected the child development results. First, the increased odds of UTI only occurred when the pregnancy was a girl, and developmental problems occurred in both boys and girls. Second, the greatest effects occurred among mothers who were in the third trimester of pregnancy at the time of the earthquake, with negative effects on child development concentrated in cases where mothers were in the first or second trimester of pregnancy. The exception was the effect of stress on the increased likelihood of the child having problems related to ADHD. Recalling the results of table **??**, the increased likelihood of ADHD was strongest in girls who were in the third trimester of the intrauterine period, which coincides with the result of increased urinary infection. Therefore, the effect of stress on the increased odds of ADHD in girls may be influenced by an indirect effect of stress, an increase in urinary tract infections.

Table **??** shows the results of the analysis of changes in the mother's behavior during pregnancy. Conditions of malnutrition, cigarette smoking, alcohol consumption, and illicit drug use are analyzed. Column 1 shows an increase in malnutrition among pregnant women. However, a result is noticeable only among mothers of girls. The result indicates an increase of 3 percentage points in the probability of a mother who was pregnant at the time of the earthquake, and it is not possible to identify different effects between the trimesters of pregnancy. Although malnutrition problems have been identified as an important mechanism in the literature on fetal programming, it is unlikely to affect the main results of this article. First, the magnitude of the coefficient is small. And second, the rate of undernourished pregnant women in the study population is only 5%, meaning that this possible mechanism affected few children.

The study found that maternal stress had an impact on alcohol consumption during pregnancy. The results showed that the impact was significant for mothers of girls. Mothers in the second trimester of pregnancy were more than 10 percentage points more likely to drink during pregnancy, while those in the third trimester were almost 6 percentage points less likely to drink. It's important to note that the questionnaire used in the study categorized alcohol consumption during pregnancy as never, occasional, and regular. The increase in likelihood of alcohol use was only observed in the category of occasional use.

5.4 Mother's mental health after childbirth

The results for the impact of stress on measures of postnatal development are strongly based on the hypothesis that the post-earthquake events affect the affected and control groups similarly. If there is a systematic difference between the two groups, the results found may not have been caused by the shock during pregnancy but by events later in the life cycle.

One aspect of interest in the fetal programming literature is the mental health of mothers in the postpar-

Table 7: Mother's behavior during pregnancy

	Malnutrition	Cigarettes	Alcohol	Alc very	Alc not very	Drugs
			Panel A - Entire sample			
Pregnancy	0,0222	0,0166	0,0310	0,0109	0,0201	-0,0056
1º Trimester	0,0389	-0,0131	0,0170	-0,0008	0,0178	-0,0044
2º Trimester	0,0344	0,0054	0,0909**	0,0082	0,0827**	-0,0157**
3º Trimester	-0,0053	0,0551	-0,0094	0,0243	-0,0337	0,0024
Observations	774	774	774	774	774	773
Panel B - Boys						
Pregnancy	0,0019	0,0153	0,0306	0,0086	0,0220	-0,0050
1º Trimester	0,0243	-0,0425	-0,0239	-0,0040	-0,0198	-0,0131
2º Trimester	0,0217	0,0391	0,0749	0,0156	0,0594	-0,0106
3º Trimester	-0,0366	0,0434	0,0358	0,0130	0,0228	0,0076
Observations	388	388	388	388	388	388
Panel C - Girls						
Pregnancy	0,0325*	0,0108	0,0335	0,0106	0,0229	0,0010
1º Trimester	0,0397	0,0022	0,0532	0,0027	0,0505	-0,0002
2º Trimester	0,0308	-0,0362	0,1075*	-0,0057	0,1131*	-0,0158
3º Trimester	0,0256	0,0633	-0,0567**	0,0348	-0,0914***	0,0175
Observations	386	386	386	386	386	385

tum period. Table 8 presents the results for four measures of maternal mental health, postpartum depression, stress when the children were between 2 and 3 years old, and stress and depression when the children were between 8 and 9 years old. The results indicate that mothers who were pregnant at the time of the earthquake had a lower risk of developing postpartum depression and depression when the children were between 8 and 9 years old. Therefore, either the mental health of the mothers in the periods after the birth of their children did not affect the main results of the article, or if it did, it had an effect in the sense of moderating the results, i.e., the effects of maternal stress during pregnancy may be more detrimental to child development than the results of the article indicate.

6 Final Remarks

The article explores advanced topics in early childhood development, focusing on the early stages of life. It aims to enhance our understanding of early childhood development by examining the circumstances surrounding embryonic and fetal stages. The article emphasizes the significance of this early stage in creating disparities among individuals, which start to become evident at birth and greatly influence child development throughout life. The focus is on the differing effects of a negative prenatal environment on boys and girls. While previous research recognizes the importance of the prenatal period for child development, there is limited exploration of the gender-specific impacts of adverse events in existing literature in human biology and applied social sciences. Men and women differ not only in apparent biological aspects but also in brain activity, sex-specific cognitive development, behavior, and disease occurrence due to various biological factors. Apart from natural differences in development, adverse experiences in life affect men and women differently. Specifically, a negative shock during pregnancy affects boys and girls in distinct ways, with adverse effects showing in different aspects of development and at various life stages. The article uses the occurrence of a major earthquake in Chile as an exogenous factor to induce stress in pregnant women, thereby assessing the impact of adverse environmental conditions during the embryonic and fetal periods on the development of

Table 8: Mother's mental health after childbirth

	Postpartum depression	Stress 2012	Stress 2017	Depression 2017
	Panel A - Entire sample			
Pregnancy	0,0018	-0,2234	-0,0277	-0,0529
1º Trimester	0,0714	0,4110	0,0213	-0,1084**
2º Trimester	-0,0559*	-0,3309	-0,0624	-0,0439
3º Trimester	-0,0130	-0,7371	-0,0437	-0,0062
Observations	768	773	773	773
	Panel B - Boys			
Pregnancy	-0,0096	0,5602	0,0714	-0,1056*
1º Trimester	0,0692	1,4731	0,1025	-0,1168*
2º Trimester	-0,0743	0,5949	0,0474	-0,0979
3º Trimester	-0,0144	-0,2996	0,0639	-0,0991
Observations	384	388	388	388
	Panel C - Girls			
Pregnancy	0,0229	-0,9222	-0,1231	-0,0009
1º Trimester	0,0929	-0,6244	-0,0533	-0,0919*
2º Trimester	-0,0316	-1,1201	-0,1858	0,0104
3º Trimester	-0,0103	-1,0965	-0,1493	0,0970
Observations	384	385	385	385

boys and girls throughout their life cycles. The findings indicate a tradeoff between viability and vulnerability in boys and girls. Initially, boys appear to be more sensitive to birth measures, being more affected than girls in terms of birth weight and size. Girls, on the other hand, seem to be more sensitive to post-birth development measures, especially in socio-emotional skills and the likelihood of developing mental illness. For girls aged 2 to 3 years who were exposed to stress during pregnancy, there were more significant socio-emotional problems compared to the control group, including higher levels of anxiety and depression. These effects were not observed in boys. Similar patterns were found in older age groups, with girls showing worse outcomes in socio-emotional measures and cognitive abilities. Regarding health conditions, boys showed an increased likelihood of asthma symptoms. In contrast, both boys and girls exhibited a higher likelihood of Attention Deficit Hyperactivity Disorder (ADHD), with a more significant impact on girls. The findings suggest that negative experiences during pregnancy can hinder fetal development, reinforcing the need for policies aimed at supporting pregnant women and addressing childhood poverty and inequality. Policy actions should also consider the sex of the child.

Understanding the impact of maternal stress on male and female fetuses is essential for designing policies that improve early childhood conditions and reduce social inequalities from the start. It is crucial to invest in equalizing opportunities and reducing social inequalities during the fetal development period.

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