BLADIMIR CARRILLO BERMÚDEZ

WEATHER FLUCTUATIONS, ERLY-LIFE CONDITIONS, PARENTAL INVESTMENTS, AND HUMAN CAPITAL: EVIDENCE FROM COLOMBIA

Dissertação apresentada à Universidade Federal de Viçosa, como parte das exigências do Programa de Pós-Graduação em Economia Aplicada, para obtenção do título de *Magister Scientiae*

VIÇOSA
MINAS GERAIS-BRASIL
2015

Ficha catalográfica preparada pela Biblioteca Central da Universidade Federal de Viçosa - Câmpus Viçosa

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C317w
2015

Carrillo Bermudez, Bladimir, 1988-
Weather fluctuations, erly-life conditions, parental investments, and human capital : evidence from Colombia / Bladimir Carrillo Bermudez. – Viçosa, MG, 2015.
xii, 85f. : il. ; 29 cm.

Orientador: João Eustáquio de Lima.
Dissertação (mestrado) - Universidade Federal de Viçosa.
Referências bibliográficas: f.81-85.

1. Capital humano. 2. Capital intelectual. 3. Temperatura atmosférica - Efeito fisiológico. I. Universidade Federal de Viçosa. Departamento de Economia Rural. Programa de Pós-graduação em Economia Aplicada. II. Título.

CDD 22. ed. 301.09861

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APROVADA: 17 de julho de 2015.

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João Eustáquio de Lima
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A Deuse a toda a minha família.

AGRADECIMENTOS

Em primeiro lugar, agradeço a Deus pela saúde e oportunidades que tem me dado desde o início da minha vida, principalmente por ter me permitido concluir mais uma etapa da minha vida.

Aos meus pais, Marieta Bermúdeze Manuel Carrillo, que sempre me apoiaram na minha vida, em especial, nos meus estudos.À Universidade Federal de Viçosa e ao Departamento de Economia Rural, por ter me dado a oportunidade de estudar o mestrado.

Ao meu orientador no mestrado, João Eustáquio de Lima, pela confiança depositada em mim mesmo nos momentos mais difíceis. Ao meu co-orientadorEvandro Camargo Teixeira, e aos demais professores que participaram da minha formação durante o mestrado.

Esta dissertaçãofoi beneficiada das discussõescom WilmanIglesias, Danyelle Brancoe Marcelo Dias, sempre dispostos a dar bons conselhos. Gostaria de agradecer também aos amigos de todas as fases da minha vida, em especial os colegas da Economia Aplicada.

A todos os funcionários do Departamento de Economia Rural, em especial Margarida, Carminha, Anízia, Tedinha, Cassiana, Romildo, Brilhante, Russo, Helena, Otto, Élida e Leoni.

A todos aqueles que direta ou indiretamente, perto ou longe, me incentivaram para que esta conquista se realizasse.

BIOGRAFIA

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RESUMO

CARRILLO BERMÚDEZ, Bladimir, M.Sc., Universidade Federal de Viçosa, julho de 2015. **Choques de Temperatura, Condições de Vida, Investimentos dos Pais, e Capital Humano: A Evidência da Colômbia**. Orientador: João Eustáquio de Lima. Coorientador: Evandro Camargo Teixeira.

As capacidades individuais são um determinante importante na formação de capital humano. Estudos recentes sugerem que as variações dessas capacidades decorrem das diferenças individuais nas dotações iniciais. Por sua vez, uma hipótese na literatura médica aponta que essas dotações dependem das condições ambientais no útero. Os choques climáticos são uma potencial influência das condições no útero. Os choques de temperatura podem favorecer a propagação de doenças infecciosas e trazer consequências adversas na produção de alimentos, o que pode acarretar em um maior risco de resultados adversos no nascimento. Ao mesmo tempo, o investimento parental é outro determinante importante das capacidades individuais. Os modelos neoclássicos de alocação de recursos ao interior da família sugerem que os investimentos dos pais podem ser afetados por variações nas dotações iniciais dos indivíduos. Esses fatos apontam a que a exposição a temperaturas extremas durante o período pré-natal pode afetar essas dotações, os investimentos parentais e, por sua vez, a formação de capital humano. Dadas essas considerações, o objetivo deste trabalho é explorar as seguintes questões no contexto colombiano. Primeiramente, busca-se entender a relação entre a exposição a mudanças de temperatura durante o período pré-natal e as dotações inicias. Em seguida, pretende-se avaliar o efeito das condições de temperatura sobre o investimento parental em capital humano. Por fim, investigam-se as consequências da exposição fetal a choques de temperatura sobre o capital humano. A metodologia explora flutuações aleatórias na temperatura que resultam de desvios da temperatura média de cada município após controlar todos os fatores sazonais e mudanças comuns em todos os municípios. Os resultados são divididos em duas partes. Em primeiro lugar, verificou-se que a exposição a ondas de calor tem consequências adversas sobre as dotações iniciais. O momento mais importante é o primeiro trimestre, onde foram encontrados os maiores efeitos. Os efeitos são maiores para as crianças de mães que vivem em áreas rurais. O segundo conjunto de resultados mostra que a exposição precoce a ondas de calor diminui o investimento dos pais em cuidado de saúde infantil e escolaridade. Na maioria dos casos, o momento mais importante é o primeiro trimestre. Foram encontradas

diferenças em investimentos de cuidados de saúde da criança por sexo e área urbana/rural. Especificamente, os maiores efeitos estão nos meninos e em crianças das áreas urbanas. Além disso, verificou-se que a formação de capital humano é afetada negativamente. De fato, indivíduos expostos a temperaturas mais elevadas no útero são mais propensos a ser analfabeto e ter menos anos de estudo durante a infância. A interpretação desses resultados é que, dados preços constantes em qualidade e quantidade da criança, as variações das dotações iniciais envolvem externalidades na capacidade de investimento dos pais. Entretanto, isto não é tudo o que está acontecendo. Em vez disso, as dotações iniciais estão positivamente relacionadas à taxa de retorno do investimento e os pais investem até onde o retorno marginal é igualado ao custo marginal. Assim, as consequências negativas sobre as dotações iniciais da exposição fetal a ondas de calor resultam em um menor retorno para o investimento e os pais respondem realocando os recursos.

ABSTRACT

CARRILLO BERMÚDEZ, Bladimir, M.Sc., Universidade Federal de Viçosa, July, 2015**. Weather Fluctuations, Erly-life Conditions, Parental Investments, and Human Capital: Evidence from Colombia.** Advisor: João Eustáquio de Lima. Co-advisor: Evandro Camargo Teixeira.

Individual capabilities are an important determinant of human capital formation. Recent studies suggest that variations in capabilities stem from individual differences in initial endowments. In turn, a hypothesis in the medical literature points out that the endowments depend on environmental conditions in *utero.* Weather shocks are a potential influence of conditions in-utero. Temperature shocks can have adverse consequences on disease environment, and food production, which could increase the risk of adverse birth outcomes. At the same time, parental investment is another important determinant of individual capabilities. The classical economic models of intra-household resource allocation suggest that birth-endowments may affect parental investment decisions. Thus, prenatal exposure to extreme temperatures may affect birth endowments, parental investments and, in turn, human capital formation. We aim to explore the following issues in the Colombian context. First, we seek to understand the relationship between prenatal exposure temperature changes and birth-endowments. Second, we assess how early temperature conditions affects parental investment in human capital. Finally, we will study how human capital consequences of fetal exposure to temperature shocks. Our methodology uses a within-municipality identification strategy. Our findings are divided into two parts. First, we found that exposure to heat waves has adverse consequences on the initial endowments. The most important timing is the first trimester, since we found greater effects. The effects are greater for children from mothers living in rural areas. The second set of results shows that early exposure to heat waves decreases parental investment in child health care and schooling. In most cases, the most important timing is the first trimester. We found differences by sex and urban/rural status in child health care investments. Specifically, the effects are greater for boys and urban children. In addition, we found that human capital formation is adversely affected. Indeed, individuals exposed to higher temperatures in utero are more likely to be illiterate and have fewer years of education during childhood. Our favorite interpretation is that, given constant prices of child quality and quantity, variations in initial endowments involve externalities in human capital. But we find this is not all

that is going on. Rather, birth-endowments are positively related to marginal returns of investment and parents invest to the point where marginal return is equal to marginal cost. Thus, the negative consequences on the initial endowments results in lower return to investment and parents respond by reallocating resources.

CHAPTER 1

INTRODUCTION

1.1.CONTEXT

The accumulation of human capital is the backbone of any modern economy. There is a growing consensus that education is an effective mechanism for poverty reduction and a key to innovation and economic growth. In view of this, international agencies have promoted the expansion of education as a primary component of development. Consequently, the role of improving education has been a central part of the strategies of most countries.

Individual capabilities are an important determinant of human capital(HECKMAN; STIXRUD JORA; URZUA, 2006).Recent studies suggest that inequalities in capabilities emerge from differences in endowments, where endowments are characteristics, for example, of health or cognitive abilities, determined before human capital accumulation process (CUNHA; HECKMAN, 2008, 2009). The consequences of impairments in initial endowments can be mitigated or exacerbated by parental investment. The seminal study by Becker and Tomes (1973) suggests that impairments in endowments increase the cost of child quality, which discourages investment in human capital. This implies that the optimal choice would be to invest less in children with worse birth-endowments. At the same time, a medical literature argues that poor birth outcomes may adversely affect these endowments.For example, it has been documented that low birth weight might lead to brain damage and impair the growth of brain structures related to learning (ABERNETHY; PALANIAPPAN; COOKE, 2002; HACK; KLEIN; TAYLOR, 1995; LEWIS; BENDERSKY, 1989). Along these lines, poor environmental conditions in utero have been shown to have adverse consequences on birth outcomes (ALMOND; MAZUMDER, 2011; CURRIE; NEIDELL; SCHMIEDER, 2009; ROCHA; SOARES, 2015).

Taken together, these facts suggest that weather shocks could have long-term impacts on human capital accumulation of cohorts exposed prenatally during these periods. Episodes of extreme heat can adversely affect birth outcomes and, thus, initial endowments through disease environment, agricultural productionand maternal stress. Heat waves favor the survival of vectors that transmit diseases such as malaria, which can harm the fetus through direct transmission from the mother and/or oxygen deprivation related to anemia (CRIMMINS; FINCH, 2006). In addition, weather shocks can adversely affect agricultural production and, in turn, reduce nutrient intake due to lower food production.Furthermore, a pregnant woman may be more susceptible to heat stress (PRENTICE *et al*., 1989; STRAND; BARNETT; TONG, 2011; WELLS; COLE, 2002), andstress has been related to increases levels of hormones that regulate growth and development of the fetus (WADHWA *et al*., 1993). As a result, prenatal exposure to heat waves potentially would affect investment in human capital through impairments in endowments.

While there are studies providing suggestive evidence of the effects of various environmental conditions in utero on parental investment (ALMOND; EDLUND; PALME, 2009; PARMAN, 2013; VENKATARAMANI, 2012), there has been little systematic research evaluating the consequences of weather shocks. Understanding the effects of weather shocks is important in view of projections indicating that the annual temperature will increase in the next decades due to man-made pollution, which would make more frequent weather events (IPCC, 2007).

Therefore, the consequences of early exposure to heat waves may be of particular interest to policy makers.

Colombia has a temperature which varies widely through short periods of time.The country is exposed to El Niño and La Niña, which are weather events that take place, on average, every four years. In 2010, Colombia was the third most country hit by weather-related loss (GERMANWATCH, 2011). Some projections suggest that in the coming decades, weather events will affect 8 out of 10 Colombians living in vulnerable areas (Catarious and Espach 2009). It is unknown how such weather shocks have affected human capital formation in the country.

In the last decades, Colombia has made progress in human capital. Indeed, while the net enrollment in secondary education was around 20% in the early 1990s, in 2012 it was over 40% (MEN, 2010). In terms of education quality, improvements are also observed. This can be concluded from the results of PISA test (Programme for International Student Assessment), which is performed in 65 countries to 15 year old students who are doing their secondary education. The results of this test for 2006 and 2009 indicate that the country improved its performance in reading, mathematics and science(OECD, 2010). Also, recent studies have shown that poverty reductionprogramshavecontributed toimproved the education quality (ATTANASIO; MARO; VERA-HERNÁNDEZ, 2013; ATTANASIO *et al*., 2010).

Despite the improvements mentioned above, Colombia remains a country behind in human capital. For example, in the results of the PISA 2009, the Colombian students were among the last 10 in the three assessment areas. Specifically, the country ranks 56 in mathematics, 53 in science and 50 in reading. Also, Colombia was the third country with the lowest percentage of students in higher levels in mathematics. This low performance in terms of quality of education is also observed in primary education. This is reflected in the results of the TIMSS (Trends in International Mathemathics and Science Study). Among 48 countries surveyed, the Colombian students are placed at 42 in science and 40 in math. Within the country, disparities are also observed not only in terms of educational quality, but also in terms of coverage. While about 48% of students entering the education system in rural areas culminates secondary education, this figure corresponds to 82% of students in urban areas (BARRERA, 2014).

Given the backlog in education mentioned above, it is of great interest to understand the causes of human capital formation. There is a growing consensus that variations in initial endowments and early investment are the major cause of inequalities in human capital. In this study, we will argue that climate change may have long-lasting intergenerational effects on human capital accumulation in Colombia. Our argument relies on the literature mentioned earlier and the increasing incidence of extreme weather episodes due to global warming.Motivated by these considerations, the purpose of this dissertation is to investigate empirically the questions listed below.

1.2.RESEARCH QUESTION AND CONTRIBUTION

Human capital is an important determinant of economic success. We aim to explore the following issues in the Colombian context. First, we seek to understand the relationship between temperature shocksin utero and birth-endowments. Second, we assess how such an exposure affects parental investment in human capital.

There are two literatures related to our study. The first is focused on studying the relationship between temperature shocks and birth outcomes. Among the most important studies are Deschenes, Greenstone, and Guryan (2009) and Andalón et al. (2014). On the one hand, Deschenes, Greenstone, and Guryan (2009) found that fetal exposure to heat waves is associated with a greater likelihood of low birth weight in U.S. On the other hand, Andalon et al (2014) focus on the Colombian rural population and their contribution is to use a broader set of birth outcome measures. They find that heat extreme episodes adversely affect birth outcomes. This literature, therefore, provide evidence that exposure to heat waves impair birth-endowments.

The second literature related to our study estimates the relationship between exposure to a poor environment inutero and investment in human capital. In Tanzania, Adhvaryu and Nyshadham (2014)show that individuals exposed to iodine supplementation in utero are more likely to be breastfed and vaccinated. Venkataramani (2012)shows that fetal exposure to malaria decreases the likelihood that children are enrolled in school at an early age. To our knowledge, only Rosales (2014) have studied early weather conditions and human capital investments. They found that fetal exposure to El Niño implies lower breastfeeding duration and nutrient intakes. However, this study does not disentangle the effect of temperature from rainfall and it may be important in practice.

Our study makes a few contributions to literature. First, we build on Andalon et al (2014) by estimating the effects of early weather conditions on birth outcomes for the entire urban population of Colombia. The impacts of temperature changes might be different between urban and rural population. While changes in income could be the main mechanism through which weather shocks could affect the birth outcomes in the rural population, this mechanism may play a minor role or none in the urban population. Therefore, studying the urban population would offer relevant information about the importance of biological mechanisms. In addition, we examine whether there are gender differences. This is of particular interest in view of the literature on “fragile males”, which supports the provocative evidence that male fetuses are more vulnerable to detrimental influences in utero than female fetuses (ALMOND; MAZUMDER, 2011; ERIKSSON *et al*., 2010; KRAEMER, 2000).

Second, we see our study as a first attempt to showthe systematic importance of early temperature conditions on human capital investments.Most of previous studies have investigated the influence of unique and uncommon historical events and the validity of its conclusions to the world today may be questionable. In contrast, the Earth’s climate is expected to become hotter in the near future, which would increase the frequency of heat extreme episodes.

Third, we use a broader set of parental investment measures. Most of previous studies use limited measures or rely on indirect evidence. For example, Almond, Edlund, and Palme (2009) argue that parents adopt reinforcing strategies because the effect of fetal exposure to the radioactive fallout on cognitive skills was greater in poor families. This evidence is compelling, but it turns out be only suggestive. In contrast, we use direct measures of parental investment such as preschool attendance and child care. Fourth, we also offer interesting new evidence of potential mechanisms. In particular, we investigate whether prenatal exposure to heat waves involves changes in fertility decisions.This is important in view that families with unhealthy children could change their future demand for children (SCHULTZ, 1997), which would affect investment in child quality as predicted by the quantity-quality model of fertility (BECKER; LEWIS, 1973). Hence, if there are significant effects on fertility it would be evidence suggesting that variations in initial endowments involve externalities in the ability of parents to invest in human capital.

In Colombia, the education programs do not take account that the parental behavior may potentiate or annihilate the effect of such interventions. For example, a family participating in *Familias en Acción* could use the monetary transfer to invest only in the most capable child, which would increasethe inequalityin well-being. Alternatively, if parents compensate the differences in initial endowments, then parents would use the money transfer to invest in the least capable child,which may reduce the inequality.Our study highlights the importance of taking into account the behavior of families in designing of these interventions.

Our study makes also a clarion call to the climate change policies. Our study suggeststhat the design of these policies should take into account the potential improvements in the accumulation of human capital. Finally, we also highlight the importance of prenatal interventions as a mechanism to reduce disparities in human capital. This is of particular interest in view of the growing evidence indicating that interventions focused on the prenatal period are more effective and substantially less expensive to be implemented (DOYLE *et al*., 2009). This is especially important in the context of Colombia because current policies are focused on the population over six years old.

1.3.Hypothesis

- ✓ Prenatal exposure to heat waves negatively affects birth outcomes, and parental investments.

1.4.OBJECTIVES

1.4.1. General Objective

- ✓ Our main objective is to study the relationship between early temperature conditions, birth-endowments, and parental investments in human capital.

1.4.2. Specific Objectives

- ✓ To determine the impacts of heat waves on birth outcomes.
- ✓ To analyze the effect of prenatal exposure to temperature shocks on parental investments in development activities, health care, and schooling.
- ✓ To determine the impact of temperature shocks in-utero on illiteracy and years of schooling.

CHAPTER 2
BACKGROUND

2.1. THEORETICAL FRAMEWORK

We begin this section by describing the classic models by Becker and Tomes (1976), and Pollak and Taubman (1982). These studies investigate how parental investment in human capital responds to variations in initial endowments. In the second part of this section we describe the recent contributions that describe how a shock in utero can affect the initial endowments and, subsequently, parental investment.

The relationship between child endowments and parental investments in human capital has been subject to debate for several decades. Parents may respond compensating or reinforcing difference in birth-endowments. For example, parents may invest in higher quality education in infants who were less healthy at birth.In this case, parents would have a compensatory behavior. Alternatively, parents could invest more in the education of infants who were healthier at birth. In this case, parents would have a reinforcement behavior. According to Becker and Tomes (1976), the parental investment depends of its returns. From this point, the returns to parental investments are influenced by the initial endowments of children. Thus, the optimal investment in each child is achievement when the expected marginal return equals the marginal cost of investment. A negative health shock increases investment costs (e.g, due to higher medical expenses). In turn, an increase in the cost of the investment could involve a reduction in returns. Then, it would be less attractive for parents to invest in infants born with poor health. This implies that parents optimally choose to reinforce the differences in endowments.

Behrman, Pollak, and Taubman (1982) extend the study by Becker and Thomes (1976) by adding parental concern for the future welfare of children. Inequality in the future welfare between siblings is influenced by differences in parental investment in human capital. Behrman, Pollak, and Taubman (1982) account for this by adding the difference in expected earnings of children in the parental utility function. Under this framework, a health shock causes uncertainty in the expected earning differential and, therefore, affects parental investment decisions. Under the assumption that parents are averse to differences in the earnings of their offspring, they will respond by investing more in less healthy infants. Thus, parents choose to compensate for differences in the endowment at birth.

More recent studies have contributed to the understanding of the relationship between birth endowments, and parental investment (CUNHA; HECKMAN; SCHENNACH, 2010; CUNHA; HECKMAN, 2007; HECKMAN, 2007; YI *et al.*, 2014) In these models, the prospects of the life cycle is a key element through which an early shock affect the accumulation of human capital. The basic intuition of these models is that skills can be seen as anaccumulative process in which the skills acquired today depends on the skills accumulated in the past. That is, more skills accumulated in the past will create more skills in the future. This process is known as self-productivity of human capital (CUNHA;HECKMAN, 2007). Also, returns to parental investment are determined by the initial set of skills, relationship which is known as complementary dynamic (CUNHA; HECKMAN, 2007). Importantly, the stock of skills can be influenced by the families, since they can remedy or exacerbate the negative early shocks. Thus, an early shock may have a persistent effect.

Another important feature of these models is related to the degree of substitutability between first and second period investments.In the case of perfect substitutability, it would be optimal to concentrate all investments in one period and no investments during the low-return period.One implication of this is that parents will adopt compensation strategies since a prenatal shock would reduce the return of postnatal investment.Conversely, perfect complementarity implies reinforcement strategies.

We now present a formal description of the model by Cunha, Heckman, and Schennach (2010) and Cunha and Heckman (2007). As a starting point, human capabilities are a multi-dimensional concept. Such dimensions can be cognitive, non-cognitive, or health-related. In the optimization problem, families decide the money and time investment in human capital formation. Parental investment is allowed to interact with the stock of acquired skills, and early shocks. The production function of child's skills in the period *t* can be written as:

$$\theta_{kt} = G_k(\theta_{kt-1}, I_{kt-1}, W_p, \varepsilon_{t-1}) \qquad (1)$$

whereθ is the skill *k*. The total parental investment is *I*. The household wealthis represented by the vector *W*. The term εrepresents random shocks.

The parental investments *I* of the period *t*-1 is a function of acquired skills and shocks occurring on this period. This can be written as follows:

$$I_{kt-1} = F_k(\theta_{kt-1}, W_p, \varepsilon_{t-1}) \qquad (2)$$

In order to understand the relationship between prenatal shocks, birth-endowments, and parental investments, let us assume that there are two periods. The first period represents birth, and the second is childhood. The production function of child in the first period and the prenatal investment can be expressed as:

$$\theta_{k1} = G_k(\theta_{k0}, I_{k0}, W_p, \varepsilon_0) \quad (3)$$

$$I_{k0} = F_k(\theta_{k0}, W_p, \varepsilon_0) \quad (4)$$

In this case, θ_{k1} represents birth-endowments, and θ_{k0} skills of genetic character. The term ε_0 would be environmental shocks in-utero. In our study, this term would represent temperature shocks. Such temperature shocks can affect directly birth outcomes through biological mechanism. Also, such shocks can affect indirectly birth outcomes through changes in prenatal investments, which would be the investment channel.

Based on this model, we can deduct the effect of prenatal exposure to heat waves on parental investment in the second period as follows:

$$\frac{\partial I_{k1}}{\partial \varepsilon_0} = \frac{\partial I_{k1}}{\partial \theta_{k1}} \left(\frac{\partial \theta_{k1}}{\partial \varepsilon_0} + \frac{\partial \theta_{k1}}{\partial I_{k0}} \frac{\partial I_{k0}}{\partial \varepsilon_0} \right) \quad (5)$$

The right side of (3) shows that there are several channels through which a shock in utero can affect parental investment. A shock in utero affects initial endowments through biological and prenatal investment channels.Thus, if such a shock has a negative biological effect and reduces prenatal investment, then, it implies adverse consequences on birth-endowments. The final effect on parental investment is determined by the sign of $\partial I_{k1}/\partial \theta_{k1}$, which depends on the elasticity of substitution between prenatal and postnatal investments. As a result, a temperature shock in utero would have adverse consequences if there is a low elasticity of substitution.

The effect of prenatal exposure to temperature shocks on skills in the second period can be expressed as follows:

$$\frac{\partial\theta_{k2}}{\partial\varepsilon_0} = \frac{\partial\theta_{k2}}{\partial\theta_{k1}}\left(\frac{\partial\theta_{k1}}{\partial\varepsilon_0} + \frac{\partial I_{k1}}{\partial\varepsilon_0}\right) \qquad (6)$$

The first term on the right is a combination of self-productivity of human capital and the biological effect. The direction of the effect of this term is unambiguously negative. The right side shows a combination of self-productivity of human capital and parental investment response to prenatal shocks, which it is likely to be negative if there is a low substitutability between prenatal and postnatal investment.

2.2.EMPIRICAL STUDIES

In this section, we present a brief review of empirical works related to our study. We divide this review into two parts.The first part consists of studies investigating the relationship between prenatal exposure to temperature shocks and birth outcomes.The second is concentrated in the literature investigating the effect of poor environmental conditions in utero on parental investment.

2.2.1.Temperature and Birth Outcomes

Most of the studies investigating the relationship between temperature and birth outcomes use birth weight as a measure of birth outcomes. Also, much of the evidence comes from the epidemiological literature. Recently, economists have also been active in demonstrating that fetal exposure to temperatureshocks could impair birth outcomes. Surprisingly, the most convincing evidence comes from works in economics. In this section, we make a brief review of the literature in general.A full review of this subject can be found in Strand, Barnett, and Tong (2011).

One of the first papers documenting a correlation between temperature and birth outcomes is Wells and Cole (2002). These authors used cross-country data and found that in countries with higher temperature there is a higher rate of low birth weight. Because low and high temperature countries differ in many aspects, cross-country regressions are unlikely to reveal the causal effect of weather conditions. Their only remedy for omitted variable biases was to include geographic characteristics, per capita GDP, and infant mortality rate as controls variables. This appears, at least to us, to be insufficient sinceunobserved factors (e.g, quality of health system)could vary across countries. Furthermore, birthweight indices are likely to be subjectedto measurement error. To the extent that measurement error is noisier in poor countries, it would also lead to a bias in cross-country regressions.

Using a sample of 12,500 individuals born between 1950 and 1956 in a Scottish city, Lawlor, Leon, and Smith (2005)assess the relationship between temperature and birth weight.The authors found that increases in temperature during the first trimester of pregnancy are associated with decreases in birth-weight.They also find a positive relationship between exposure in the third trimester and birth weight.However, they not control for seasonal factors, which is important in practice. For example, a recent study shows that maternal characteristic vary across birth season (BUCKLES; HUNGERMAN, 2013). Therefore, the negative relationship found in Lawlor, Leon, and Smith (2005) could simply reflect the fact that low socioeconomic-status mothers are more likely to conceive in warm months.Another potential problem with their study is that it does not control for rainfall and it may also be important. For example, Rocha and Soares (2015) show that rainfall shocks have adverse consequences on birth outcomes regardless temperature conditions. Thus, the omission of rainfall may imply a bias.

Elter*et al*. (2004)find a positive relationship between temperature during the second trimester and birth weight. However, these authors did not control the influence of precipitation nor seasonal factors, so their results are also potentially biased. Using data for 447,499 births between 1971 and 1986, MURRAY *et al*. (2000)also find a positive relationship.An advance of this study is that includes year and month-fixed effects and control for rainfall.However, they did not control for regional differences in both birth weight and temperature. If such regional differences are not random, then the findings from Murray et al (200) cannot be interpreted as causal.

Examining a cohort of 7,039 individuals born in New Zealand, Tustin, Gross, and Hayne (2004)find no significant statistical correlation between temperature and birth weight.However, like previous studies, this author does not employ a convincing identification strategy.Furthermore, given the small sample size, this study may have limited statistical power.

Agay-Shay *et al*. (2013)document a significant positive correlation between temperature and the risk of congenital heart defects in a sample of 135,527 births in Israel.This is consistent with other studies in the epidemiological literature which also found that temperature is associated with risk of congenital malformation(EDWARDS, 1967; VAN ZUTPHEN; HSU; LIN, 2014).

The seminal study in economics isDeschenes, Greenstone, and Guryan (2009), whostudies the relationship between temperature and birth outcomes by controlling forrainfall andcounty, year and month fixed effects. They used a sample of 37 millions of births in U.S and confirm a negative relationship between heat waves and birthweight. In addition, they find that this relationship was statistically significant in the second and third trimesters for babies of white mothers.For babies from African-American mothers, exposure to heat waves in any trimester of pregnancy has adverse effects on birth outcomes.As a final exercise,they projected that climate change will reduce birth weight between 0.22 and 0.36% in 2099.

Pereda, Menezes, and Alves (2014)use data at the State level in Brazil to study the effects from temperature changes on risk of neonatal death and birth weight.Using a similar strategy to Deschenes, Greenstone, and Guryan (2009), they found that increases in temperature increases the risk of neonatal death.Furthermore, they found that exposure during the second trimester increases the risk of low birth weight.

In rural Colombia, Andalon, *et al* (2014) move in relation to previous studies by using a broader set of birth outcomes. In particular, the authors use the Apgar score, a clinical test which evaluates the health of the newborn[1]. These authors found that increases in temperature imply adverse consequences onApgar score.These estimated impacts are small in magnitude.For example, exposure to temperatures that are one standard deviation above the historical average implies a 0.30% reduction in the probability of the normal Apgar score.Unlike previous studies, the authors found a small and not significant effect on birth weight.They recognized the possibility that this is due to the so-called fetal selection bias. This bias could arise if the temperature shocks increase fetal deaths and, therefore, birth outcomes are only observed for surviving fetuses. This bias would lead to underestimate the impact of temperature if the surviving fetuses are the healthiest.

[1] The Apgar test is a clinical test that is given to the newborn in which five parameters are assessed. The parameters evaluated are: muscle tone, respiratory effort, heart rate, reflexes and skin color. The test provides a total score between 0 and 10, where a higher score means more healthy(ALMOND; CHAY; LEE, 2005).

2.2.2. Birth-Endowments and Parental Investment

There is a broad set of studies investigating how parental investment responds to variations in birth outcomes. Much of this evidence is concentrated in developed countries. These studios also tend to use birth weight as a measure of endowments. However, birth weight is not a perfect measure of birth-endowments because it does not capture all dimensions of them. While birth weight seems a good proxy for cognitive skills (FIGLIO *et al*., 2014), it is a poor measure of newborn health (ALMOND; CHAY; LEE, 2005).

A pioneering study in this area is Datar, Kilburn, and Loughran (2010).Using a family-fixed effects estimator, they found that children born with normal weight (≥2,500 gr.) are more likely to be breastfed and enrolled in preschool programs.Hsin (2012)used a similar strategy, but employed better measures of parental investment.In particular, Hsin (2012) uses the time spent by the mother with her children in stimulating activities such as reading, hobbies and homework together.She found that parents spend more time with children who had normal birth weight.She also found differences by socio-economic status.Indeed, she found that more-educated mothers spend more time with low birth-weight children.

Using a sample of 60,000 children, Aizer and Cunha (2012)used measures of parental investments based on psychological tests which assess expressions of affection, handling, and child care.Another difference compared with previous studies is that Aizer and Cunha (2012) considered different measures of endowments, such as body size and head circumference.Overall, they found that better endowments predict greater parental investment. A drawback in this study, as pointed out by Almond and Mazumder (2013), is that its measures of parental investment could reflect the innate personality of children, which may be correlated with the quality of their interactions with their parents.

The above studies use estimators based on family-fixed effects and rely on the assumption that specific differences across siblings are uncorrelated with birth-endowments and parental investment. Some studies have questioned this assumption and, therefore, included a broader set of controls that vary across siblings. For example,Datar, Kilburn, and Loughran (2010)included family income during pregnancy,mother's age and education, antenatal visits, andthe use of alcohol during pregnancy.They found that their estimates do not changewhen these variables are included. However, they recognize the possible influence of unobservedfactors.

Some studies have used estimators based on twin-fixed effects to eliminate the influence of prenatal unobserved investments that are correlated with postnatal investments. Using longitudinal data,Royer (2009)found that birth weight is not related to measures of parental investments such as breastfeeding duration.Using the same sample, Currie and Almond (2011)analyzed a broader set of parental investment measures, such as reprimand, praise, and caress. In most of cases, Currie and Almond (2011)found also no significant effects. However, the sample used in these studies has a limited number of observations, aboutof 1,500 twins, whichimplies little statistical power to detect any small effect.Furthermore, it is unclear the external validity from these studies since the occurrence of twins is a rare event and, therefore, represent a very small fraction of the population.

As an alternative remedy to the variable omitted bias, other studies have used specific historical episodes as a source of variation in birth endowments. The strategy of these studies has been to analyze how an exogenous change in environmental conditions affects parental investments. Using the introduction of malaria eradication programs in Mexico, Venkataramani (2012)estimate the effect of prenatal exposure to malaria on school entry age. They found that individuals with lower exposure to malaria started school at an earlier age.A limitation of this study is that not used other measures of parental investments.

Adhvaryu and Nyshadham (2014)use an iodine supplement program in Tanzania as a source of variation.They show that the program increased the likelihood that children receive vaccinations and breastfeeding.They also revealed positives externalities in siblings of exposed children and provide suggestive evidence that their results are not explained by changes in fertility or investments at birth. In view of the medical evidence suggesting that iodine deficiency can impair neurological development, the authors argue that their results are explained by variations in cognitive skills. However, the evidence of externalities in siblings suggests that other channels are driving their results.An alternative possibility is that maternal awareness of child health care could be improved, which in turn would affect both birth-endowments and investment decisions(ALMOND; MAZUMDER, 2013).

Halla and Zweimüller (2014) studied parental response to radioactive fallout caused by the Chernobyl accident in Austria.Their parental investment measures underlie on fertility and maternal labor participation.They find that families with low socioeconomic status responded by reducing fertility, while those with high socioeconomic status increased labor force participation.They concluded that parents adopted compensatory behaviors. One problem with these conclusions is that fertility and labor supply decisions are not inputs. Rather, these variables are potential links between shocks in *utero* and investment decisions.The authors provide no direct evidence of how parental investment in education or health care, for example, changed as a result of exposure to radioactive fallout.Further, while a reduction in family size increase the ability of parents to invest, they may even reduce investment due to a higher price of child quality(BECKER; LEWIS, 1973). Therefore, the results of Halla and Zweimüller (2014) should be carefully interpreted.

Almond, Edlund, and Palme (2009)study the effects of radioactive fallout caused by the Chernobyl accident in Switzerland and also provideindirect evidence. As a starting point, they assess whether the public spending on primary education was hit nine years after the accidentand found nosignificant effects.As a second exercise, the authors estimate the impacts of the accident on tests of cognitive skills separately for children from low and high socio-economic status. They find that the effects are larger for children from low socio-economic status.Since there is no reason to believe that families with a low educational level were more exposed to the accident, they interpret this result as evidence that parents have a reinforcement behavior. Although plausible, this is not necessarily the truth of what happened.In fact, the authors recognize that other factors could explain the differences in the estimated effects of the accident. For example, they suggest the possibility that less educated families had been less able to mitigate the effects of the nuclear accident.It is, therefore, difficult to draw definitive conclusions about parental responses.

For Ecuador, Rosales (2014) investigated the effects of prenatal exposure to El Niño on parental investment. She measures the exposure to this phenomenon as the number of months during the period that the child was exposed in utero to precipitation levels one standard deviation above the historical average. She finds that children with higher exposure to the phenomenon were negatively affected in terms of nutrient intake, breastfeeding and cognitive skills. The author presents evidence suggesting that changes in family income could be the channel which explains her results.

CHAPTER 3
Empirical Strategy and Data

3.1. ECONOMETRIC MODEL

We regress each outcome y on a set of temperature exposure measures. Separate exposure measures for each trimester during pregnancy are included simultaneously. We use the following specification:

$$y_{ijmt} = \alpha + \sum_q^3 \beta_q \bar{T}_{ijmtq} + \gamma Z + \mu_j + \zeta_m + \lambda_t + \xi_{ijmt} (7)$$

The dependent variables include birth outcomes and parental investment. In the following sections, we describe all variables used in this study. $\bar{T}_{ijmtq}$ is the exposure to temperature of trimester q of gestation for the individual i, born in the municipality j,in the month m,and in the year t. Z is a vector of control variables including maternal and child characteristics. Z also includes precipitation and precipitation squared. In our analysis of parental investments, we also include a vector of municipality specific time trends. The inclusion of these trends is possible in the analysis of parental investments because we have children who were born within a period of time longer than two years before survey. The terms μ are birth municipality fixed effects. The birth month and year fixed effects are ζ, and λ, respectively. The term of random error is ξ.

The validity of any estimate of the impact of prenatal exposure to temperature fluctuations based on (7) relies crucially on the assumption that its estimate will produce unbiased estimates of β_q. For this, we require the following identification assumption:

$$Cov(\bar{T}_{ijmtq}, \xi_{ijmt} \mid Z, \mu_j, \zeta_m, \lambda_t) = 0 \forall q = 1, 2, 3 \quad (8)$$

The plausibility of this assumption rests on three components. First, we use high frequency information to construct a municipality-by-month weather dataset, which is merged with microdata by using the date and place of birth. Second, we use temporary temperature deviations from historical averages to limit the influence of unobservable correlated to temperature levels. Third, all our specifications condition on a full set of municipality, month and year fixed effects in order to account for time invariant characteristics, aggregate shocks, and seasonal factors that might be related to temperature shocks. Thus, our approach exploits fluctuations in temperature from municipality-specific deviations in temperature after controlling for all seasonal factors and common shocks to all municipalities. This variation is assumed to be random and therefore should not be correlated with omitted determinants of birth outcomes or parental investments. Given these conditions, we are able to identify the causal impact of early temperature shocks using ordinary least squared (OLS) on (7).

Despite random variation in temperature argued above, there are challenges to our identification strategy. First, poor conditions in utero due to heat waves may increase the rate of fetal death, as hypothesized by Lam and Miron (1996). Empirically this is problematic because we only observe birth outcomes for those born alive. If those weaker fetuses are the most likely to die, then would arise a selection bias. This bias may also arise if surviving fetuses are those from mothers with better economic status. A second potential problem is that changes in temperature may affect the probability of conception. If the least fertile or healthy mothers are less likely to conceive during heat wave episodes, then exposure to temperature would be correlated with unobserved factors. A third potential source of bias is that parents can respond to temperature shocks migrating. As a result, we would assign incorrectly fetal exposure to temperature changes for these infants. In the presence of these sources of bias, our estimates may underestimate the true effect of temperature shocks.

We do not have a perfect remedy for these potential threats, but we can investigate its relevance. In particular, we investigate as total births responds to changes in temperature. Insignificant estimates would suggest that fetal selection bias caused by fetal death is not present. We also investigate other sources of bias by running placebo regressions. Favorable results in these tests do not allow us to rule out the possibility that our estimates are plagued by these sources of bias. Thus, we conservatively interpret our estimates as lower bounds of the true effect of prenatal exposure to temperature shocks.

In this study, most of the dependent variables are dummies.For these variables, we estimate linear probability models (LPM).Therefore, the relevant coefficients are interpreted as the average marginal effect.To account for heteroskedasticity and correlation between individuals within municipalities, we use robust standard errors clustered at municipality level. We do not use logit or probit models for two main reasons. First, we are interested in the average treatment effect (ATE), which corresponds to the average marginal effect if the orthogonality conditions are satisfied, and estimates from the logit, probit and LMP provide broadly similar estimates of the average marginal effect.Second, the use of the logit and probit models implies a great computational burden. Indeed, the inclusion of municipality fixed effects implies the inclusion of over 1,000 regressors, making impractical to use these models.

3.2.DATA

Our study requires: 1) weather data with detailed geographic and temporal information; 2) microdata with exact information on the place and date of birth; 3) microdata with information on birth outcomes; 4) microdata with information on measures of parental investment and human capital. We describe the handful of suitable datasets below.

3.2.1.Weather Data

We use monthly temperature and precipitation data provided by Matsuura and Willmott (2012). This dataset provides estimates of climate around the world at a level of about 56x56 kilometers. These estimates are based on information collected from several nearby weather stations. The data provided geographical coordinates that identify the spatial location of weather information, constituting a monthly series for the period 1900-2010. In order to construct a municipality-by-month of weather panel over this period, we use a strategy similar to Rocha and Soares (2015). To start with, we compute the centroid for each municipality. Then, using the centroid for each of these municipalities, we located the four nearest nodes. Thus, we build monthly series of temperature and precipitation for each municipality as the weighted average of estimates related to the four nodes. We use the inverse of the distance of each municipality to each of the four nodes as weights. This information is merged with the microdata described in the next section.

We build our measure of temperature fluctuations (T_{jmt}) for the municipality j, month *m* and year *t*, as follows:

$$T_{jmt} = \frac{temperature_{jmt} - \overline{temperature_{jm}}}{sd(temperature_{jm})} \quad (9)$$

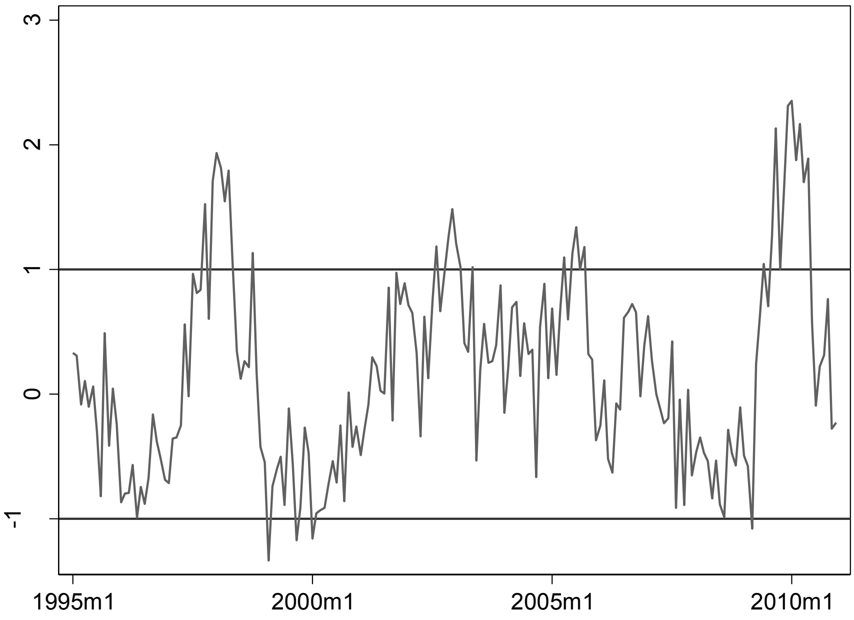
$sd(.)$is the historical standard deviation of temperature. This measure indicates how many standard deviations the temperature is above (or below) the historical average for a given municipality and point in time. We calculate the historical average and standard deviation for each municipality using information from the period 1900-2010. Our measures of prenatal exposure to temperature changes during the q trimester for each individual are calculated as follows:

$$\bar{T}_{ijmtq} = \left(\sum_{\Gamma=3q-2}^{3q} T_{j\Gamma}\right)/3 \quad (10)$$

whereΓ are corresponds to the months of gestation. This calculation assumes that individuals were nine months in uterus. Thus, the use of this variable would lead to a measurement error in exposure of individuals who were born prematurely. Our main response to this concern is that to the extent that this measurement error is important, it will lead to a downward bias in the effect of temperature changes, and if so, our results showing large impacts would become even more telling. As a robustness analysis, we estimate the impact of temperature changes on birth outcomes using the sample including all infants and a subsample that excludes premature births.

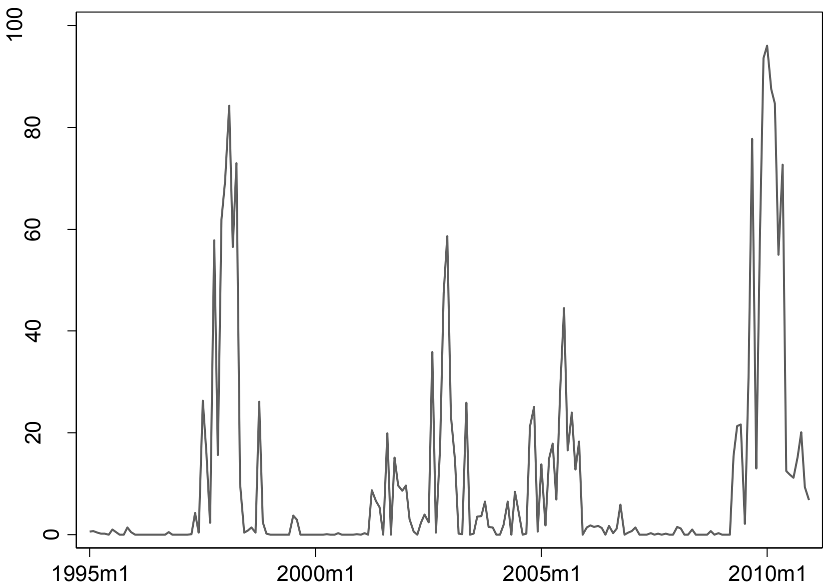
Figure 1 shows the evolution of standardized temperature for the period 1995-2010. The figure shows that the temperature varies widely over time. The years with highest temperature are 1998 and 2010.It is also observed that the temperature is almost never below one standard deviation from the historical average, while periods of heat waves are more frequent. Figure 2 shows the spatial distribution of the incidence of heat waves (defined as 1.5 standard deviations above the historical average). The figure shows that the incidence of high temperatures also varies significantly across municipalities. Episodes of extreme heat occur, on average, in 10% of the Colombian municipalities. Yet, there are periods with pervasive heat waves hitting almost 80% of the municipalities and periods with no municipality experiencing a heat wave.

Figure 1. Z-scores of Temperature by Month over the period 1995-2010 in Colombia



Source: Research results.

Figure 2. Distribution of the Heat Shocks by Municipality over the period 1995-2010 in Colombia



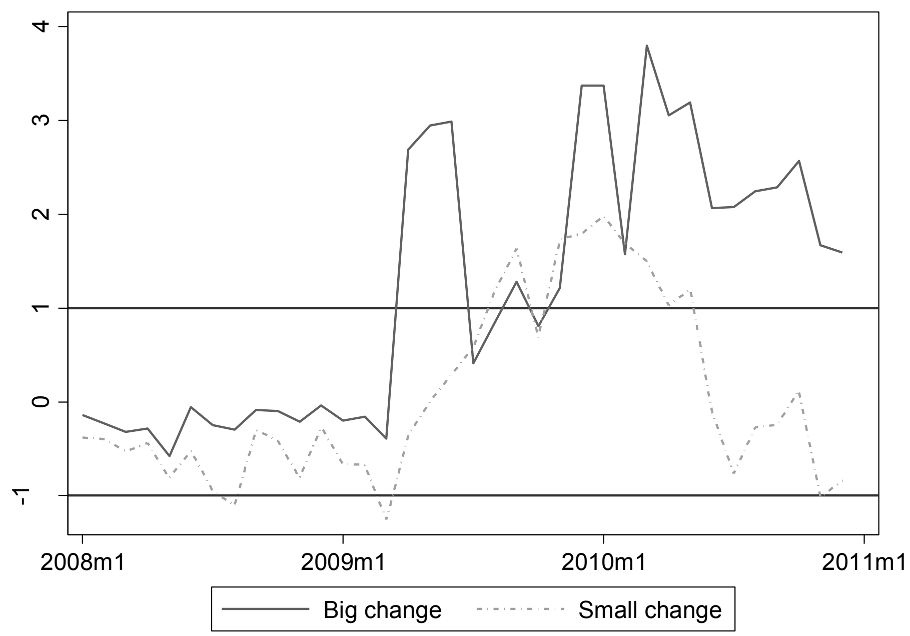
Source: Research results.

3.2.2. Natality Data

From of Administrative Department of Statistics (DANE), birth certificate microdata are publicly available from 2009. We obtained these data for 2009 and 2010 within the 1120 municipalities in Colombia- approximately 1.4 million birth records. The data include the date of birth, duration of pregnancy, sex, birth weight, Apgar scores and maternal characteristics such as marital status, age and education. Importantly, the information about municipality of residence is also provided. The sample is limited to births that were certified by a physician, which implies a reduction of about 2%. We also dropped the 269,642 births with either less than 37 weeks gestation or missing gestation information. The final sample consists of about 1,057,912 births. The dependent variables of interest are 5 minute Apgar score, low 5 minute Apgar score (<8), and low birth-weight (≤2,500 gr.). Using the municipality of residence of mother and date of birth, we merge these data with our weather database. Thus, we identify prenatal exposure to temperature changes for each infant who was conceived between 2008 and 2010.

The short period of study raises some concerns about the variation in the prenatal exposure to temperature. Limited variation in temperature may lead to earlier less precise estimates of the effect of temperature conditions. However, this has little empirical support. Indeed, there is substantial variation both over time and space in that short window of time. Figure 3 shows that while in most months of 2008 the temperature is located practically in its historical average, it is placed between 2 and 4 standard deviations above the historical average from 2009. In fact, there are months where temperature is placed nearly 4 standard deviations above the historical average. The figure also shows that these changes were heterogeneous across municipalities. For example, in the first months of 2010 there are municipalities where the temperature is at about 1 standard deviation above average, while in others it is at almost 4 standard deviations above. This suggests that there is substantial variation in that narrow window of time, which allows us to assess the effects of temperature shocks.

Figure 3. Z-scores of Temperature by Month over the period 2008-2010 in Colombia



Source: Research results.

Table 1 shows a statistical summary of natalitydata. The average of 5 minute Apgar score is 9.63. About 1% of the infants in the sample are born with a low Apgar score. Almost 3% of infants had low birth weight. Of all infants born, 99% were singletons, and 51% are male. Approximately 80% of infants have mothers living in urban areas. Also, 23% of mothers are under 20 years of age, 18% were married, and 80% have low educational attainment (<12 years of schooling).

Table 1. Summary Statistics for Colombian Natality Data, 2009-2010

	N	Mean	Standard Deviation	Min	Max
Birth outcomes:					
5 Minute APGAR Score	1,045,357	9.63	0.67	1	10
Low 5 Minute APGAR (<8)	1,045,357	0.01	0.11	0	1
Low Birth Weight (≤2,500 gr)	1,056,410	0.03	0.17	0	1
Child characteristics					
Singleton	1,057,912	0.99	0.12	0	1
Male	1,057,912	0.51	0.50	0	1
Birth month:					
January	1,057,912	0.08	0.28	0	1
February	1,057,912	0.07	0.26	0	1
March	1,057,912	0.09	0.28	0	1
April	1,057,912	0.08	0.27	0	1
May	1,057,912	0.08	0.27	0	1
June	1,057,912	0.08	0.27	0	1
July	1,057,912	0.08	0.28	0	1
August	1,057,912	0.09	0.28	0	1
September	1,057,912	0.09	0.29	0	1
October	1,057,912	0.09	0.28	0	1
November	1,057,912	0.08	0.27	0	1
December	1,057,912	0.08	0.27	0	1
Mother characteristics:					
Urban residence	1,041,285	0.80	0.40	0	1
Age <20	1,057,912	0.23	0.42	0	1
Age 20-24	1,057,912	0.29	0.46	0	1
Age 25-29	1,057,912	0.23	0.42	0	1
Age 30-34	1,057,912	0.15	0.35	0	1
Age 35-44	1,057,912	0.09	0.29	0	1
Age 45 +	1,057,912	0.00	0.04	0	1
Married	1,057,912	0.18	0.38	0	1
Low education (<12 years of schooling)	1,057,912	0.80	0.40	0	1

Source: Research results. Notes: Except for 5 Minute APGAR Score, all variables are dummies.

3.2.3. Colombian Demography and Health Surveys

To evaluate the effects of early weather conditions on investment, we use the Colombian Demography Health Survey (DHS), which is a nationally representative survey of women of childbearing age and is conducted every five years from 1986. We use the DHS of 2005 and 2010 because, exceptfor 1990 DHS, the DHS of previous years do not provide information about the municipality of residence. Without this information we are unable to identify prenatal exposure to temperature fluctuations. Our sample consists of 31,557 children born between 1999 and 2010. This survey provides information about the exact date of birth, but the municipality of birth is not directly known. But the survey provides information on the years of residence in the current municipality. From this information we can identify children born in the current municipality of residence. Limiting the sample to these children implies a loss of 13% in the number of observations. We also dropped 536 dead children and 2,860 children who are less than 6 months old at the time of the survey. The size of our basic sample consists of 23,790 observations, but it varies across estimates due to presence of missing values. All calculations are performed using the weights provided by the survey.

This survey allows us to study two types of parental investment measures: health care and development activities. As measures of health care, we use breastfeeding duration and vaccinations. To study breastfeeding, we focus on children over two years old. Most of children in this group is not breastfeeding. This variable is subject to measurement error because it is based on retrospective information. Our identification strategy requires that this measurement error is uncorrelated with prenatal exposure to temperature changes. This seems plausible.

We constructed dummies indicating vaccination status for each of the following variables: hepatitis B, diphtheria-pertussis-tetanus (DPT), polio and measles. For hepatitis B, we created a dummy variable indicating whether a child received the third dose, which is expected to be received between 6 and 18 months of age. For DPT and polio, we use created dummies indicating whether a child received the second or third doses. The DPT doses are expected to be received between six and eighteen months of age, while polio doses are expected in children between 4 and 18 months of age. For measles, we create a binary variable equal to one if the child received the first dose, which is expected to be received between 12 and 15 months old. The models using the measles vaccine status as the dependent variable excludes children who are under the age of twelve months.

The variables regarding development activities are available only in the 2010 DHS. One perhaps more appropriate measure would be the time spent on these activities, as in Hsin (2012). However, DHS does not provide this information and, therefore, we are limited to examine whether parents do or not these activities. We use dummy variables for playing, walking, reading, and singing activities.

Table 2 shows a statistical summary of data. About 75% of children in the sample received the hepatitis B vaccine. The percentages of children who received the DPT, polio, and measles doses are high, ranging between 92 and 94%. The mean of breastfeeding duration is 13 months. The percentage of children doing development activities with their parents varies widely across each type of activity. For example, while the percentage of children who perform playing activities with their parents is 90%, this figure corresponds to 50% for reading activities. The average age of children is around 31 months. Almost 38% of children are first born. The fraction of singletons is 98%. About 70% of children in the sample come from urban areas, 30% have mothers who are heads of households. Around 13 and 22% of the children are from teenage and married mothers, respectively.

Table 2. Summary Statistics for Colombian Demography and Health Surveys, 2005 and 2010

	N	Mean	Standard Deviation	Min	Max
Parental measures:					
Hepatitis B	22,898	0.75	0.43	0	1
DPT	22,838	0.94	0.23	0	1
Polio	23,213	0.94	0.24	0	1
Measles	20,687	0.92	0.26	0	1
Breastfeeding duration (in months)	12,149	12.95	9.30	0	54
Playing	13,277	0.91	0.28	0	1
Walking	13,277	0.80	0.40	0	1
Reading	13,277	0.50	0.50	0	1
Singing	13,277	0.76	0.43	0	1
Child characteristics:					
Age (in months)	23,790	31.61	15.59	6	59
Male	23,790	0.51	0.50	0	1
First born	23,790	0.38	0.49	0	1
Singleton	23,790	0.98	0.12	0	1
Urban residence	23,790	0.71	0.45	0	1
Birth month:					
January	23,790	0.08	0.27	0	1
February	23,790	0.08	0.27	0	1
March	23,790	0.08	0.28	0	1
April	23,790	0.08	0.28	0	1
May	23,790	0.08	0.27	0	1
June	23,790	0.08	0.27	0	1
July	23,790	0.09	0.28	0	1
August	23,790	0.08	0.28	0	1
September	23,790	0.09	0.29	0	1
October	23,790	0.08	0.28	0	1
November	23,790	0.08	0.28	0	1
December	23,790	0.09	0.28	0	1
Mother characteristics:					
Household head	23,790	0.31	0.46	0	1
Age <20	23,790	0.13	0.34	0	1
Age 20-24	23,790	0.29	0.45	0	1
Age 25-29	23,790	0.25	0.43	0	1
Age 30-34	23,790	0.18	0.38	0	1
Age 35-44	23,790	0.15	0.36	0	1
Age 45 +	23,790	0.01	0.07	0	1
Married	23,790	0.22	0.41	0	1
Low education (<12 years of schooling)	23,790	0.84	0.37	0	1

Source: Research results.
Notes: All calculations use the sample weights. Except for age, and Breastfeeding duration, all variables are dummies.

3.2.4. Colombian Census 2005

To investigate the potential effects of early temperature shocks on parental investment in education, we use microdata from the census. We use data from the most recent census, 2005. The Integrated Public Use Microdata Series (IPUMS) provides a one percent sample. Data on month, year and place of birth of individuals are provided. However, IPUMS reclassified birthplace in groups of municipalities. For example, Ebejico, St. Jerome, and Sopetran municipalities represent a group. Thus, the 1120 Colombian municipalities are classified in about 533 groups, indicating that on average a group contains two municipalities. Given this, we can identify only the municipality group of birth and not the municipality. To link this information with our weather data, we build a municipality-group-by-month of weather panel over the period 1900-2005. These data were merged using the date and municipality group of birth.

From census data, we use two measures of parental investment. The first is a dummy variable indicating preschool attendance for a child between three and six years of age. The second is a dummy variable indicating whether a child between seven and nine years old never went to school. The reasoning for this variable is that children who never went to school receive less investment in education. We focus on this age group because in Colombia the minimum school age is six years. We do not include older children because the decision to go to school is more likely to depend on them. We also study the effects of prenatal exposure to temperature shocks on other measures related to human capital formation. Specifically, we use illiteracy status and education years for children between seven and nine years of age.

From census data, we study two additional variables. The first is a dummy variable indicating whether a child between two and nine years old has a younger brother from the same mother. The second variable of interest is maternal labor force participation status for children between one and nine years old. We are interested in analyzing how fertility and labor force participation are affected by exposure during pregnancy to the temperature shocks.

In summary, we have created four sub-samples from census data, which consist of the following age groups: three-six, seven-nine, two-nine, and one-nine. In order to obtain representative estimates of the population, all calculations are performed using the expansion factor provided by the IPUMS. Table 3 provides a statistical summary of the variables used. The first thing that can be observed is that about 60% of children between 3 and 6 years old are attending a preschool program. About 11% of children between 7 and 9 years old was never enrolled in school and cannot read or write. Although the mean of these two variables are similar, the correlation coefficient between them is 0.54. This indicates that there are also illiterate children who ever attended school. A child of the same age group, on average, has 1.96 years of schooling. About 70% of all children in the sample reside in urban areas. Around 84% of infants have mothers who are white. The percentage of children with mothers who are heads of households is low, 15%. Of all children in the sample, 30, 85 and 34% have mothers who are married, employed and have less than 12 years of schooling, respectively.

Table 3. Summary Statistics for Colombian Census Sample 2005

	N[1]	Mean	Standard Deviation	Min	Max
Parental measures:					
Preschool attendance	2,763,980	0.61	0.49	0	1
Never went to school	2,085,049	0.11	0.32	0	1
Illiteracy	2,088,887	0.11	0.31	0	1
Years of schooling	2,085,049	1.96	1.18	0	5
Child characteristics:					
Age (in years)	6,207,297	5.05	2.58	1	9
Male	6,207,297	0.51	0.50	0	1
First born	6,207,297	0.40	0.49	0	1
Urban residence	6,207,297	0.72	0.45	0	1
Birth month:					
January	6,207,297	0.08	0.27	0	1
February	6,207,297	0.08	0.27	0	1
March	6,207,297	0.08	0.27	0	1
April	6,207,297	0.08	0.27	0	1
May	6,207,297	0.08	0.28	0	1
June	6,207,297	0.08	0.27	0	1
July	6,207,297	0.08	0.27	0	1
August	6,207,297	0.08	0.27	0	1
September	6,207,297	0.08	0.28	0	1
October	6,207,297	0.09	0.29	0	1
November	6,207,297	0.09	0.28	0	1
December	6,207,297	0.08	0.27	0	1
Mother characteristics:					
White	6,207,297	0.84	0.36	0	1
Household head	6,207,297	0.15	0.36	0	1
Age <20	6,207,297	0.17	0.38	0	1
Age 20-24	6,207,297	0.28	0.45	0	1
Age 25-29	6,207,297	0.24	0.43	0	1
Age 30-34	6,207,297	0.17	0.38	0	1
Age 35-44	6,207,297	0.13	0.34	0	1
Age 45 +	6,207,297	0.01	0.08	0	1
Married	6,174,405	0.30	0.46	0	1
Low education (<12 years of schooling)	6,207,297	0.85	0.35	0	1
Employed	6,141,604	0.34	0.47	0	1
Number of children	5,236,366	2.93	1.80	1	16

Source: Research results. Notes: (1) represents the expanded sample using factor provided by the IPUMS. All calculations use the sample weights.Except for years of schooling and age (in years), all variables are dummies.

3.2.5. Additional statistics

Table 4 presents the descriptive statistics of the variables of interest by area of residence (urban/rural) and child's sex. For birth outcomes, we observed few differences between urban and rural infants. For example, the percentage of low birth weight is identical between urban and rural infants. For vaccines, it is only observed urban/rural differences in measles vaccine (94 *vs* 89%). Table 4 also shows that rural children, on average, have a longer duration of breastfeeding (14.3 *vs* 12.4 months). We observe urban/rural differences in developing activities. For example, while 53% of children in urban areas perform reading activities with their parents, this figure is 41% for children in rural areas. There are pronounced differences in parental investments in education. For instance, the fraction of urban children attending a preschool program is 54% higher than that of rural children. The percentage of children who have never been to school is 60% higher for the rural area. Illiteracy differences are substantial. Indeed, illiteracy rate is 200% higher in rural area.

Table 4. Means by Child's Sex and Residence Area (Standard deviation in brackets)

	Urban		Rural		Male		Female	
	N(1)	Mean	N(1)	Mean	N(1)	Mean	N(1)	Mean
Birth outcomes:								
5 Minute APGAR Score	822,775	9.63	206,442	9.64	536,112	9.62	509,245	9.65
		[0.66]		[0.71]		[0.69]		[0.65]
Low 5 Minute APGAR (<8)	822,775	0.01	206,442	0.02	536,112	0.01	509,245	0.01
		[0.10]		[0.13]		[0.11]		[0.10]
Low Birth Weight (≤2,500 gr)	828,713	0.03	211,186	0.03	541,765	0.02	514,645	0.04
		[0.17]		[0.17]		[0.15]		[0.19]
Investments measures:								
Hepatitis B	15,145	0.75	7,753	0.75	11,639	0.75	11,259	0.74
		[0.43]		[0.42]		[0.42]		[0.43]
DPT	15,110	0.95	7,728	0.93	11,604	0.94	11,234	0.94
		[0.22]		[0.26]		[0.24]		[0.23]
Polio	15,302	0.94	7,911	0.94	11,798	0.94	11,415	0.94
		[0.24]		[0.24]		[0.23]		[0.24]
Measles	13,673	0.93	7.014	0.89	10,501	0.92	10,186	0.92
		[0.25]		[0.30]		[0.26]		[0.26]
Breastfeeding duration	8,175	12.42	3,974	14.38	6,155	12.82	5,994	13.07
		[9.41]		[8.83]		[9.31]		[9.29]
Playing	8,476	0.93	4,801	0.87	6,792	0.91	6,485	0.92
		[0.26]		[0.33]		[0.29]		[0.28]
Walking	8,476	0.83	4,801	0.74	6,792	0.80	6,485	0.80
		[0.38]		[0.44]		[0.40]		[0.40]
Reading	8,476	0.53	4,801	0.41	6,792	0.48	6,485	0.52
		[0.50]		[0.49]		[0.50]		[0.50]
Singing	8,476	0.79	4,801	0.67	6,792	0.74	6,485	0.78
		[0.40]		[0.47]		[0.44]		[0.41]
Preschool attendance	1,994,842	0.68	769,138	0.44	1,414,102	0.61	1,349,878	0.62
		[0.47]		[0.50]		[0.49]		[0.49]
Never went to school	1,536,998	0.10	548,051	0.16	1,061,658	0.12	1,023,391	0.11
		[0.29]		[0.37]		[0.33]		[0.31]
Human capital accumulation:								
Illiteracy	1,538,618	0.07	550,269	0.21	1,063,656	0.12	1,025,231	0.09
		[0.25]		[0.41]		[0.32]		[0.29]
Years of schooling	1,536,998	2.03	548,051	1.78	1,061,658	1.90	1,023,391	2.02
		[1.16]		[1.21]		[1.17]		[1.19]

Source: Research results.

Note: (1) represents the expanded sample using factor provided by the IPUMS. Standard deviations are in brackets. Notes: all calculations use the sample weights.

By sex, we note that girls have low birth weight rate than double that of boys, while there are no differences in other birth outcomes. We see little difference in vaccines. The table shows that on average girls are breastfed longer and are less likely to perform developing activities with their parents. We also note that parents do not invest differently in education between boys and girls. In human capital, the table reveals that boys have higher rates of illiteracy and fewer years of schooling than girls.

3.2.6. Other Data

To investigate the income mechanism, we use data provided by the Center for Economic Development Studies (CEDE) from Andes University. The CEDE has collected information at the municipal level on a set of indicators for the period 1993-2010. In this study, we used data on population and tax revenues. Using tax revenue data, we created a proxy for municipal GDP using the following procedure. First, we calculate the tax revenue share of each municipality into the department for each year during the period of study. Second, we multiply this share by the departmental GDP, which provides us with the proxy for municipal real GDP. The following variable is created to be used in the analysis:

$$Early\ GDP\ shocks_{it} = \log(GDP_{it}) - \log(\overline{GDP_i}) \quad (11)$$

This variable indicates the percentage variation in the per capita GDP of the municipality (or municipality group) *i* in year *t* in relation to the average GDP per capita. The average per capita GDP of each municipality is calculated using the period 1993-2010.

CHAPTER 4

RESULTS FOR TEMPERATURE FLUCTUATIONS AND BIRTH-ENDOWMENTS

4.1.MAIN RESULTS

Table 5 presents the results for Apgar score, low Apgar score, and low birth-weight. Each column is from a separate regression. These results include controls related child and mother characteristics mentioned above.Column (1) indicates that exposure during the first trimester to an increase of one standard deviation in temperature reduces the Apgar score at around 0.008 points.This result is significant at the 1% level. In magnitude, the estimated effect is small relative to the mean of the Apgar score(0.08%≈100*0.008/9.6).Exposure during the other trimesters has no statistically significant effects.

The results in column (2) indicate that an increase of one standard deviation in temperature in the first trimester implies a statistically significant increase of 0.10 percentage points in the likelihood of low Apgar score. This impact is large in magnitude(10%≈100*0.00102/0.001), indicating the presence of disproportionate effects across Apgar score distribution. Column (3) shows that increases in temperature during the first trimester significantly increase the risk of low birth weight.In magnitude, one additional standard deviation in temperature implies in an increase of 2% in the risk of low birth weight.

Table 5. Estimated Impact of Temperature Changes on Birth Outcomes in Colombia, 2009-2010

	5 Minute APGAR Score (1)	Low 5 Minute APGAR (<8) (2)	Low Birth Weight (≤2,500 gr) (3)
Prenatal exposure during:			
1st trimester	-0.00873	0.00103	0.000631
	[0.00324]***	[0.000258]***	[0.000346]*
2st trimester	0.00308	-0.0000950	-0.000169
	[0.00272]	[0.000235]	[0.000254]
3st trimester	-0.000443	-0.0000560	0.000402
	[0.00294]	[0.000237]	[0.000310]
Number of observations	1,028,828	1,028,828	1,039,502
Child characteristics	Yes	Yes	Yes
Mother characteristics	Yes	Yes	Yes
Month fixed effects	Yes	Yes	Yes
Municipality fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes

Source: Research results.
Notes:Robust standard errors (in brackets) are clustered at municipality level. Child characteristics include sex, and singleton status. Mother characteristics include age dummies, married, low and missing education dummies. Month fixed effects are dummy variables for birth months. Municipality fixed effects are dummies for municipality of residence of mother. Year fixed effects is a dummy variable for birth in 2010. Urban dummy is also included.*Yes* that means that the group of variables is included in the regressions. *** p<0.01, ** p<0.05, * p<0.1.

Table 6 presents separate regressions for urban and rural on the effects of temperature changes on birth outcomes. Panel A shows the results for the sample of newborns urban, while Panel B corresponds to rural infants. The results in column (1) indicate no urban/rural substantial differences in Apgar score, although the coefficient for rural infants is slightly smaller and not significant. Column (2) shows larger effects for rural infants on the likelihood of low Apgar score. Indeed, the coefficient of the first trimester of exposure for rural is approximately 1.6 times larger than that for urban. Column (3) shows substantial differences for likelihood of low birth weight. For urban, the coefficient of the first trimester of exposure is smaller and statistically insignificant. For rural, the coefficient is substantially larger, about 4 times larger. An increase of one standard deviation in temperature during the first trimester implies in an increase of 5% in the risk of low birth weight[2].

Table 6. Estimated Impact of Temperature Changes on Birth Outcomes by Residence Areain Colombia, 2009-2010

	5 Minute APGAR Score (1)	Low 5 Minute APGAR (<8) (2)	Low Birth Weight (≤2,500 gr) (3)
	Panel A: Urban		
Prenatal exposure during:			
1st trimester	-0.00909	0.000905	0.000316
	[0.00337]***	[0.000273]***	[0.000351]
2st trimester	0.00456	-0.000216	-0.000181
	[0.00314]	[0.000263]	[0.000279]
3st trimester	-0.00129	-0.000110	0.000447
	[0.00279]	[0.000237]	[0.000350]
Number of observations	818,855	818,855	824,683
	Panel B: Rural		
Prenatal exposure during:			
1st trimester	-0.00626	0.00147	0.00152
	[0.00404]	[0.000591]**	[0.000788]*
2st trimester	-0.00237	0.000441	-0.000226
	[0.00309]	[0.000438]	[0.000626]
3st trimester	0.00487	0.0000598	0.000364
	[0.00318]	[0.000452]	[0.000600]
Number of observations	205,007	205,007	209,704
Child characteristics	Yes	Yes	Yes
Mother characteristics	Yes	Yes	Yes
Month fixed effects	Yes	Yes	Yes
Municipality fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes

Source: Research results.
Notes: Robust standard errors (in brackets) are clustered at municipality level. Child characteristics include sex, and singleton status. Mother characteristics include age dummies, married, low and missing education dummies. Month fixed effects are dummy variables for birth months. Municipality fixed effects are dummies for municipality of residence of mother. Year fixed effects is a dummy variable for birth in 2010.*Yes* that means that the group of variables is included in the regressions. *** p<0.01, ** p<0.05, * p<0.1.

Table 7 investigates whether there are sex differentials in the effects of early temperature conditions. The findings in column (1) suggest small differences in the

[2] This estimate results from dividing the coefficient on the average of the dependent variable.

estimated impacts for Apgar score.In the risk of low Apgar score, the estimates suggest that exposure had a much greater impact on males(0.14 percentage points) than on females (0.05 percentage points). Given a baseline probability of 1%for boys, exposure to an increase of one standard deviation in temperatureincreased the probability of lowApgar score in 14%for that. Column (3) reveals insignificant effects for the boys on the likelihood of low birth weight. For girls, exposure during the third trimester was significant at the 10% level.Everything else being equal, an increase of one standard deviation in temperature during the third trimester is associated with a 2.2% increase in the risk of low birth weight for that group.This lack of pattern through birth outcomes does not support the hypothesis of fragile males.

Table 7. Estimated Impact of Temperature Changes on Birth Outcomes by Sex in Colombia, 2009-2010

	5 Minute APGAR Score (1)	Low 5 Minute APGAR (<8) (2)	Low Birth Weight (≤2,500 gr) (3)
	Panel A: Male		
Prenatal exposure during:			
1st trimester	-0.00907	0.00149	0.000675
	[0.00369]**	[0.000353]***	[0.000423]
2st trimester	0.00343	-0.000372	-0.00000283
	[0.00304]	[0.000312]	[0.000309]
3st trimester	-0.000718	-0.000199	-0.0000670
	[0.00362]	[0.000337]	[0.000334]
Number of observations	527,579	527,579	533,039
	Panel B: Female		
Prenatal exposure during:			
1st trimester	-0.00842	0.000516	0.000564
	[0.00313]***	[0.000286]*	[0.000575]
2st trimester	0.00267	0.000199	-0.000356
	[0.00280]	[0.000274]	[0.000384]
3st trimester	-0.000207	0.000109	0.000899
	[0.00264]	[0.000253]	[0.000479]*
Number of observations	501,249	501,249	506,463
Child characteristics	Yes	Yes	Yes
Mother characteristics	Yes	Yes	Yes
Month fixed effects	Yes	Yes	Yes
Municipality fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes

Source: Research results.

Notes: Robust standard errors (in brackets) are clustered at municipality level. Child characteristics include singleton status. Mother characteristics include age dummies, married, low and missing education dummies. Month fixed effects are dummy variables for birth months. Municipality fixed effects are dummies for municipality of residence of mother. Year fixed effects is a dummy variable for birth in 2010. Urban dummy is also included. *Yes* that means that the group of variables is included in the regressions. *** p<0.01, ** p<0.05, * p<0.1.

Table 8 presents separate estimates for unmarried and low education mothers.Columns (1) and (2) show that the effects of exposure during the first trimester on Apgar score are slightly larger for these groups.The effect of exposure in the first trimester on the risk of low birth weight is slightly larger for unmarried mothers (Column 5). Compared to the baseline result, this coefficient changes from 0.000631 to 0.000822.One difference with the baseline results is that now exposure during the third trimester has a significant effect at 10% level.For least-educatedmothers, the coefficient of the first trimester fell to 0.000598 and is estimated with less precision. Overall, the results suggest small difference by maternal characteristics.

Table 8. Estimated Impact of Temperature Changes on Birth Outcomes by Maternal Characteristic in Colombia, 2009-2010

	5 Minute APGAR Score		Low 5 Minute APGAR (<8)		Low Birth Weight (≤2,500 gr)	
	Mother is not married	Mother's education (< 12years)	Mother is not married	Mother's education (< 12 years)	Mother is not married	Mother's Education (< 12 years)
	(1)	(2)	(3)	(4)	(5)	(6)
Prenatal exposure during:						
1st trimester	-0.0102	-0.00922	0.00118	0.000963	0.000774	0.000545
	[0.00358]***	[0.00359]**	[0.000282]***	[0.000298]***	[0.000380]**	[0.000393]
2st trimester	0.00284	0.00278	-0.000112	0.0000488	-0.000120	-0.0000346
	[0.00282]	[0.00273]	[0.000263]	[0.000252]	[0.000276]	[0.000295]
3st trimester	-0.00000297	-0.000245	-0.0000687	-0.0000428	0.000499	0.000485
	[0.00316]	[0.00335]	[0.000249]	[0.000262]	[0.000283]*	[0.000309]
Number of observations	829,478	821,064	829,478	821,064	838,357	830,282
Child characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Mother characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Month fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Municipality fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes

Source: Research results.

Notes: Robust standard errors (in brackets) are clustered at municipality level. Child characteristics include sex, and singleton status. Mother characteristics include age dummies, married, low and missing education dummies. Month fixed effects are dummy variables for birth months. Municipality fixed effects are dummies for municipality of residence of mother. Year fixed effects is a dummy variable for birth in 2010. Urban dummy is also included. *Yes* that means that the group of variables is included in the regressions.*** p<0.01, ** p<0.05, * p<0.1.

4.2.ROBUSTNESS OF FINDINGS

We perform a number of robustness tests designed to assess the validity of our identification strategy. Specifically, we explore whether our findings are influenced by the exclusion of preterm infants, fetal death,selective timing of conceptions and migrations. In general, the results from these robustness checks are reassuring.

4.2.1. Adding Preterm Births

Our first robustness analysis is to estimate our models including preterm infants. We had excluded this group because infants born prematurely are more likely to have adverse birth outcomes. Furthermore, using the sample of infants with normal length of gestation, we can more accurately assign temperature exposure.The results of this exercise are presented in Table 9. Column (1) suggests broadly similar results for Apgar score.The coefficient of the first trimester goes from -0.00942 to -0.00873. For the probability of low Apgar score, there are also quantitatively similar results, but now the coefficient of the first trimester increases slightly (Column 2).There are notable differences for the likelihood of low birth weight.The coefficient of the first trimester falls slightly but now is not significant. This indicates that measurement error could be important in this birth outcome.

Table 9. Estimated Impact of Temperature Changes on Birth Outcomes in Colombia, 2009-2010 (Adding preterm infants)

	5 Minute APGAR Score	Low 5 Minute APGAR (<8)	Low Birth Weight (≤2,500 gr)
	(1)	(2)	(3)
Prenatal exposure during:			
1st trimester	-0.00942	0.00125	0.000551
	[0.00329]***	[0.000285]***	[0.000579]
2st trimester	0.00344	-0.000140	-0.0000410
	[0.00280]	[0.000256]	[0.000574]
3st trimester	-0.00176	0.0000275	0.0000476
	[0.00311]	[0.000265]	[0.000413]
Number of observations	1,277,295	1,277,295	1,293,123
Child characteristics	Yes	Yes	Yes
Mother characteristics	Yes	Yes	Yes
Month fixed effects	Yes	Yes	Yes
Municipality fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes

Source: Research results.

Notes: Robust standard errors (in brackets) are clustered at municipality level. Child characteristics include sex, and singleton status. Mother characteristics include age dummies, married, low and missing education dummies. Month fixed effects are dummy variables for birth months. Municipality fixed effects are dummies for municipality of residence of mother. Year fixed effects is a dummy variable for birth in 2010. Urban dummy is also included. *Yes* that means that the group of variables is included in the regressions.*** p<0.01, ** p<0.05, * p<0.1.

4.2.2. Fetal Death

We now investigate the role of the fetal selection bias.As we mentioned before, whether the heat waves lead to more miscarriages in weak fetuses, then our estimates may underestimate the true effect of early temperature conditions.As a practical matter, we estimate the relationship between temperature conditions and the births. For this, webuild a municipality-by-month panel on births and merged it with our weather database.If such bias is present, then, we should observe a negative relationship between the births and temperature conditions. Column (1) of Table 10 presents a regression of the log of births using as explanatory variables the temperature shocks of each trimester. All coefficients are negatives, but not statistically significant. Note that this result is not driven by large standard errors. For example, the coefficient of the first trimester is -0.008, which suggests a semi-elasticity of -0.8

Table 10. Estimated Impact of Temperature Changes on Births, and Sex Ratio in Colombia, 2009-2010

	Dependent variable is log of births (1)	Dependent variable is Male (2)
Prenatal exposure during:		
1^{st} trimester	-0.00801	-0.000112
	[0.00502]	[0.000987]
2^{st} trimester	-0.00192	-0.000221
	[0.00386]	[0.000724]
3^{st} trimester	-0.000265	-0.0000880
	[0.00431]	[0.000671]
Number of observations	26,148	1,040,888
Child characteristics	No	Yes
Mother characteristics	No	Yes
Month fixed effects	Yes	Yes
Municipality fixed effects	Yes	Yes
Year fixed effects	Yes	Yes

Source: Research results.

Notes: Robust standard errors (in brackets) are clustered at municipality level. Child characteristics include sex, and singleton status. Mother characteristics include age dummies, married, low and missing education dummies. Month fixed effects are dummy variables for birth months. Municipality fixed effects are dummies for municipality of residence of mother. Year fixed effects is a dummy variable for birth in 2010. Urban dummy is also included for specification in column (2). *Yes* that means that the group of variables is included in the regressions.*** p<0.01, ** p<0.05, * p<0.1.

Column (2) presents an alternative way to investigate the presence of fetal death. Specifically, this exercise investigates whether sex ratio is affected by temperature conditions. The motivation for this comes from the literature suggesting that poor conditions in utero have worse consequences for the male fetuses (ALMOND; MAZUMDER, 2011; ERIKSSON et al., 2010; KRAEMER, 2000).Given this, if there is any fetal death bias, then we should expect that temperature shocks lower the sex ratio in favor of the girls.With this in mind, we use a dummy variable indicating the sex of the infant is male as a dependent variable. As can be seen, the coefficients of each trimester exposure have the expected negative sign, but are far from being statistically significant.Moreover, the coefficients are small in absolute value. For example, an increase of one standard deviation in temperature during the first trimester is associated with a statistically insignificant reduction of 0.01 percentage points,which corresponds to 0.02% from the baseline probability.

In sum, although we cannot rule out the possibility of a fetal selection bias, our results suggest that it is likely to play a minor role.The results in the next sub-section also support this conclusion.

4.2.3. Selective Timing of Conceptions and Migration

Another potential source of bias is that mothers might be less likely to conceive in episodes of heat. Also,if mothers believe that heat waves are likely to affect the performance of the fetus, then they could postpone their fertility decisions.There is evidence showing that fertility rates are negatively related to temperature (Lam and Miron, 1996). If mothers who change their fertility decisions are systematically different from those who do not, then our results could be biased. In addition, a bias could also arise whether mothers migrate in order to mitigate the influence of temperature shocks. The insignificant relationship found between births and temperature in the previous section does not support these possibilities. In this sub-section, we present an alternative exercise to investigate such possibilities.

Table 11 shows the results of a natural falsification test: we estimate the relationship between temperature conditions and maternal characteristics. To the extent that our estimates do not reflect the compositional changes in births due to strategic maternal behavior, prenatal exposure to temperature shocksshould not predict maternal characteristic changes. Out of the 12 estimates, only 1 was significant at the 5 percent level. We found that exposure during the second trimester is associated with higher probability of teenage mother. Given the relatively large number of observations, this significant estimatemay simply reflect sampling variation.We found no significant estimates for the probabilities of unmarried, low education, and age over 44 years. Taken together, this exercise shows that maternal characteristics do not systematically change with temperature. However, one caveat remains: our test is imperfect because it is based on observable characteristics.Still, it is possible the presence of differences in unobservable characteristics.

Table 11. Estimated Impact of Temperature Changes on Maternal Characteristics in Colombia, 2009-2010 (Falsification Test)

	Mother's age <20 (1)	Mother's age >44 (2)	Mother's education (< 12 years of schooling) (3)	Mother is married (4)
Prenatal exposure during:				
1st trimester	-0.00108	0.000148	0.0017	-0.000259
	[0.000963]	[0.000106]	[0.00126]	[0.000860]
2st trimester	0.00141	0.0000322	-0.00161	-0.000188
	[0.000600]**	[0.0000528]	[0.00118]	[0.000710]
3st trimester	-0.000439	0.0000448	0.000507	-0.000954
	[0.000911]	[0.0000550]	[0.000857]	[0.000657]
Number of observations	1,052,759	1,052,759	1,052,759	1,052,759
Month fixed effects	Yes	Yes	Yes	Yes
Municipality fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes

Source: Research results.

Notes: Robust standard errors (in brackets) are clustered at municipality level. Month fixed effects are dummy variables for birth months. Municipality fixed effects are dummies for municipality of residence of mother. Year fixed effects is a dummy variable for birth in 2010. *Yes* that means that the group of variables is included in the regressions.*** p<0.01, ** p<0.05, * p<0.1.

4.3.DISCUSSION

In sum, in utero exposure to temperature increases is associated with higher probabilities of low Apgar score and birth weight. It seems that the most important timing is the first trimester. Infants who were prenatally exposed to one higher standard deviation in temperature during the first trimester had 10 and 2% higher probabilities of low Apgar score and birth weight, respectively. One way to assess the magnitude of theestimated impacts is compare the effect of temperature conditions to the differences in birth outcomes between advantaged and disadvantagedmothers.Columns (1) and (2) in Table 12show mean birth outcomes for non-teenage, married and most-educated mothers(advantaged) and for teenage, unmarried and least-educated mothers (disadvantaged).The comparison of columns (4) and (6) show that the effects of exposure to heat waves in the first trimester on Apgar score, low Apgar score and birthweight represent, respectively, 25, 40 and 8.3% of the magnitude of the difference between advantaged and disadvantaged mothers.For the risk of low Apgar score, the effects are large.A newborn of an advantaged mother who was exposed to 2.5 higher deviations temperature during the first trimester would have a probability of low Apgar similar to that of a newborn from a disadvantaged mother who was exposed to a normal temperature.

Table 12. Comparison of mean birth outcomes by SES with the estimated effect of 1st trimester temperature changes exposure

	Mean for Advantaged group	Mean for Disadvantaged group	Diff	Coefficient Estimated 1st trim temperature
	(1)	(2)	(3)	(5)
Birth outcomes:				
5 Minute APGAR Score	9.640	9.60	0.031	-0.00873
			[0.001]***	[0.00324]***
Low 5 Minute APGAR (<8)	0.011	0.0138	-0.0026	0.00103
			[0.0002] ***	[0.000258]***
Low Birth Weight (≤2,500 gr)	0.028	0.036	-0.0076	0.000631
			[0.0004] ***	[0.000346]*

Source: Research results.
Notes: SES denotes Socio-Economic-Status.Advantaged group are newborn from non-teenage, married andmost-educated (over 12 years of schooling) mothers.Disadvantaged group are newborn from teenage, unmarried and least-educated (under 12 years of schooling) mothers. Column (3) performs *t* test on the equality of means between the advantaged and disadvantaged groups. Standard errors arein brackets. *** p<0.01, ** p<0.05, * p<0.1.

Another way to assess the size of the estimated effects is to compare the effect of fetal exposure to temperature conditions with previous estimates of the effects of other environmental risk factors. Compared with the effects of health insurance, smoking, and air pollution, our estimated impacts on birth weight are small.Using Colombian data, Camacho and Conover (2013)show that a 10% increase in health insurance coverage reduces by 11% the likelihood of low birth weight. Currie, Neidell and Schmieder (2009) show that a unit changes in carbon dioxide increased by 7% the probabilities of low birth weight in U.S. Also, Almond, Chay, and Lee (2005) show that smoking increases the incidence of low birth weight by 4%.Put another way, an exposure during the first trimester to a temperature between 2 and 5 standard deviations above the historical average would have an effect similar to the effects of exposure of these environmental risk factors.To Apgar score, exposure in the first trimester to temperature one standard deviation above the historical average have larger effects than the effects of smoking (ALMOND; CHAY; LEE, 2005), air pollution(CURRIE; NEIDELL; SCHMIEDER, 2009),health insurance(CAMACHO; CONOVER, 2013).This confirms that oureffects estimates on the Apgar score are large.

We are unable to make definitive statements on pathways through which heat waves affect birth outcomes. But we suggest possibilities.A pathway suggested by the biomedical literature is stress and there is growing evidence supporting this. Camacho (2008)shows evidence suggesting that exposure to stress caused by terrorist attacks have a negative effect on birth weight in Colombia.Currie and Rossin-slater (2013)found that exposure to stress caused by hurricanes in the U.S. substantially increased the likelihood of abnormal conditions. Our findings are consistent with this mechanism since they suggest larger effects for the first trimester of gestation.

There are other biological mechanisms through which heat waves could affect birth outcomes. The literature indicates that dehydration due to excessive sweating may affect the health of the fetus because of insufficient liquid decreases the amount of blood available to the fetus and induces uterine contractions(STAN *et al*, 2013). Increases in the spread of infections have also been cited as a potential pathway. Temperature fluctuationsdetermine the survival of viruses carrying diseases such as malaria. However, we believe that malaria is not the major reason for our findings.For example, the malaria incidence in Colombia is 0.3 deaths per 100,000 inhabitants, a figure that is 440 times lower than that for the country with the highest incidence of malaria in the world[3].

Another possible link is agricultural activity. Temperature shocks may adversely affect agricultural productivity(DESCHENES; GREENSTONE, 2007), reducing the income of rural families. In turn, reductions in income may affect birth outcomes through reductions in nutrient intake.In Colombia, agriculture is an important economic sector.Indeed, agriculture is the third sector that holds individuals into the labor market(FEDESARROLLO, 2013). Simulation exercises suggest that climate change would have a substantial effect on the Colombian GDP due to losses that would be generated in the agricultural sector (PEREIRA *et al*., 2014). In view of this, the changes in income might be an important connection between the heat wave and birth outcomes. Our results are consistent with this channel because we find considerably larger effects for mothers living in rural areas. However, this does not seem all that is going on in view of Miller and urdinola (2010).They find that infant mortality is lower in episodes of economic downturns in Colombia, suggesting that mothers increase the demand for the use of health services.This evidence suggests that there are other most important mechanisms behind our results.

[3]Seehttp://www.worldlifeexpectancy.com/cause-of-death/malaria/by-country/.

CHAPTER 5

RESULTS FOR EARLY TEMPERATURE FLUCTUACTIONS AND PARENTAL INVESTMENTS

5.1.CHILD HEALTH CARE

Table 13 shows the results for child health care. Columns (1)-(4) presents the results for vaccines, while column (5) for breastfeeding duration.We found a statistically significant reduction of exposure in the second trimester in the probability of hepatitis B vaccine (Column (1)).The point estimate is -0.019 with a standard error of 0.0067. Given the mean rate of 75%, this implies that one standard deviationabove mean in temperature lead to a 2.5% reduction in the likelihood of hepatitis B vaccine.

The results in column (2) does not show evidence that exposure to temperature in utero is statistically associated with the likelihood of DPT vaccine. Conversely, the columns (3) and (4) show that exposure during the first trimester is associated with a reduction in the probability of polio and measles vaccines.Specifically, an increase of one standard deviation implies a reduction of 0.8 and 1.04 percentage points in the probability of these vaccines, respectively. Relative to mean rates, these coefficients imply a reduction of 0.85 and 1.1%.

Table 13. Estimated Impact of Temperature Changes on Parental Investments in Health Carein Colombia, 2005 and 2010

	Vaccinations				Nutrition
	Hepatitis B (1)	DPT (2)	Polio (3)	Measles (4)	Breastfeeding duration (5)
Prenatal exposure during:					
1st trimester	-0.00587	-0.00994	-0.00806	-0.0104	-0.0125
	[0.00903]	[0.00632]	[0.00379]**	[0.00412]**	[0.207]
2st trimester	-0.0190	-0.00374	0.00212	0.00218	0.388
	[0.00674]***	[0.00389]	[0.00296]	[0.00902]	[0.296]
3st trimester	0.00864	0.00010	-0.00136	-0.00819	-0.0509
	[0.00754]	[0.00565]	[0.00443]	[0.00618]	[0.234]
Number of observations	22,777	22,715	23,090	20576	12,085
Child characteristics	Yes	Yes	Yes	Yes	Yes
Mother characteristics	Yes	Yes	Yes	Yes	Yes
Month fixed effects	Yes	Yes	Yes	Yes	Yes
Municipality fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Municipality specific time trends	Yes	Yes	Yes	Yes	Yes

Source: Research results.

Notes: Robust standard errors (in brackets) are clustered at municipality level. Child characteristics include sex, singleton status and birth order. Mother characteristics include age dummies, married, low andvariable dummy for head of household. Month fixed effects are dummy variables for birth months. Municipality fixed effects are dummies for municipality of residence of mother. Year fixed effects is a dummies for birth years. All estimations use sample weights.*Yes* that means that the group of variables is included in the regressions..*** p<0.01, ** p<0.05, * p<0.1.

Table 14 shows the results for child health care separately for urban and rural children. The results for hepatitis B vaccine reveal that there are only significant effects for children in urban areas.In absolute value, the coefficient of the second trimester is slightly larger relative to the baseline results. The lack of significance for rural areas does not seem to be explained by lack of power. Indeed, the coefficient for the rural area is substantially smaller (absolute value) relative to urban children, specifically being 4 times lower.

Table 14. Estimated Impact of Temperature Changes on Parental Investments in Health Care by Residence Areain Colombia, 2005 and 2010

	Vaccinations				Nutrition
	Hapatitis B (1)	DPT (2)	Polio (3)	Measles (4)	Breastfeeding duration (5)
			Panel A: Urban		
Prenatal exposure during:					
1st trimester	-0.00879	-0.0142	-0.00865	-0.00811	0.00591
	[0.0116]	[0.00778]*	[0.00469]*	[0.00422]*	[0.398]
2st trimester	-0.0224	-0.00269	0.00188	-0.00316	0.796
	[0.00852]***	[0.00531]	[0.00334]	[0.0109]	[0.582]
3st trimester	0.0101	-0.000107	0.000266	-0.00849	0.0666
	[0.00897]	[0.00751]	[0.00561]	[0.00738]	[0.503]
Number of observations	15,047	15,012	15,205	13,587	3,963
			Panel B: Rural		
Prenatal exposure during:					
1st trimester	0.00167	0.00309	-0.00585	-0.0147	-0.0936
	[0.0119]	[0.00723]	[0.00798]	[0.0119]	[0.246]
2st trimester	-0.00497	-0.00776	-0.00318	0.0150	0.231
	[0.0133]	[0.00835]	[0.00685]	[0.0157]	[0.367]
3st trimester	0.00439	0.00360	0.00140	-0.00680	-0.0332
	[0.0133]	[0.00827]	[0.00682]	[0.0136]	[0.286]
Number of observations	7,730	7,703	7,885	6989	8,122
Child characteristics	Ye	Yes	Yes	Yes	Yes
Mother characteristics	Yes	Yes	Yes	Yes	Yes
Month fixed effects	Yes	Yes	Yes	Yes	Yes
Municipality fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Municipality specific time trends	Yes	Yes	Yes	Yes	Yes

Source: Research results.

Notes: Robust standard errors (in brackets) are clustered at municipality level. Child characteristics include sex, singleton status and birth order. Mother characteristics include age dummies, married, low and variable dummy for head of household. Month fixed effects are dummy variables for birth months. Municipality fixed effects are dummies for municipality of residence of mother. Year fixed effects is a dummies for birth years. All estimations use sample weights. *Yes* that means that the group of variables is included in the regressions. *** p<0.01, ** p<0.05, * p<0.1.

We found a significant effect of exposure during the first trimester for the DPT vaccine in the sample of urban children. An increase of one standard deviation in temperature implies a reduction of 1.4 percentage points in the probability of receiving this vaccine. In contrast, we found no significant effects for rural children. In fact, the coefficient for the first trimesters is positive, but it turns out be very small (0.3% relative to mean rate).

The results also suggest that the relationship between prenatal exposure to temperature conditions and polio vaccination is driven by urban children. Exposure during the first trimester to temperatures one standard deviation above the mean implies a reduction of 0.8 percentage points in the probability of this vaccine in the sample of urban child. The reduction in the probability of receiving this vaccine for a rural child exposed during the first trimester to temperatures one standard deviation above mean is 0.5 percentage points, though is not statistically significant.

For measles, we also find urban/rural differences. In fact, the coefficient for rural children is almost twice times (in absolute value) than the corresponding to urban sample. However, this coefficient is only significant for the urban children.

We now explore sex heterogeneities (Table 15). For hepatitis B, we find that the coefficient of the second trimester for the boys is 2 times higher (in absolute value) the corresponding to the baseline result.The point estimate is significant at the 1% level. For girls, the same corresponding coefficient is similar to the baseline result but not significant.

For boys, we found significant effects on the first and second trimesters for the DPT vaccine (Column (2)). Column (3) shows that temperature increases during the first and third trimester have negative effects on vaccine for males. For measles (column (4)), there are significant effects only in the first trimester for boys. There are not significant effects for girls in these vaccines.

Table 15. Estimated Impact of Temperature Changes on Parental Investments in Health Care by Sexin Colombia, 2005 and 2010

	Vaccinations				Nutrition
	Hepatitis B (1)	DPT (2)	Polio (3)	Measles (4)	Breastfeeding duration (5)
			Panel A: Boy		
Prenatal exposure during:					
1st trimester	-0.00342	-0.0144	-0.0151	-0.0175	-0.363
	[0.0109]	[0.00759]*	[0.00693]**	[0.00641]***	[0.276]
2st trimester	-0.0361	-0.00873	0.00371	-0.00637	0.309
	[0.0119]***	[0.00490]*	[0.00485]	[0.0111]	[0.442]
3st trimester	0.000924	-0.00553	-0.0113	-0.0158	0.242
	[0.00937]	[0.00719]	[0.00422]***	[0.0119]	[0.347]
Number of observations	11,583	11,546	11,741	10,448	6,125
			Panel B: Girl		
Prenatal exposure during:					
1st trimester	-0.00689	-0.00882	-0.00219	-0.00611	0.596
	[0.0109]	[0.00774]	[0.00594]	[0.00557]	[0.366]
2st trimester	-0.00152	0.00358	-0.00134	0.00751	0.585
	[0.00977]	[0.00678]	[0.00509]	[0.00970]	[0.440]
3st trimester	0.0147	0.00297	0.00905	-0.00153	-0.262
	[0.0128]	[0.00760]	[0.00607]	[0.00922]	[0.388]
Number of observations	11,194	11,169	11,349	10,128	5,960
Child characteristics	Yes	Yes	Yes	Yes	Yes
Mother characteristics	Yes	Yes	Yes	Yes	Yes
Month fixed effects	Yes	Yes	Yes	Yes	Yes
Municipality fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Municipality specific time trends	Yes	Yes	Yes	Yes	Yes

Source: Research results.

Notes: Robust standard errors (in brackets) are clustered at municipality level. Child characteristics include singleton status and birth order. Mother characteristics include age dummies, married, low and variable dummy for head of household. Month fixed effects are dummy variables for birth months. Municipality fixed effects are dummies for municipality of residence of mother. Year fixed effects is a dummies for birth years. Urban dummy is also included. All estimations use sample weights. *Yes* that means that the group of variables is included in the regressions. *** p<0.01, ** p<0.05, * p<0.1.

5.2.DEVELOPMENT ACTIVITIES AND SCHOOLING

Table 16 presents the results for parental investment in development activities and schooling.Column (1) shows significant effects for playing activities in the first and third trimester.Children who were exposed to one standard deviation higher in temperature during the first trimester have a reduction of 1.3 percentage points in the likelihood of playing activities.The corresponding reduction for the third trimester is 0.8 percentage points.

Table 16. Estimated Impact of Temperature Changes on Parental Investments in Stimulant activities and Schoolingin Colombia, 2005 and 2010

	Stimulation activities				Schooling	
	Playing	Walking	Reading	Singing	Preschool attendance	Never went to school
	(1)	(2)	(3)	(4)	(5)	(6)
Prenatal exposure during:						
1st trimester	-0.0135	-0.0146	-0.00808	0.00627	-0.0119	0.0368
	[0.00653]**	[0.00912]	[0.00879]	[0.00811]	[0.00298]***	[0.00325]***
2st trimester	0.00582	0.00273	0.00422	-0.0055	-0.00907	0.0112
	[0.00520]	[0.0101]	[0.0123]	[0.00887]	[0.00324]***	[0.00496]**
3st trimester	-0.00897	-0.0178	-0.00156	0.00633	-0.0485	-0.000166
	[0.00523]*	[0.00872]**	[0.00876]	[0.00778]	[0.00537]***	[0.00486]
Number of observations	13,206	13,206	13,206	13,206	272,522	202,181
Child characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Mother characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Month fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Municipality fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Municipality specific time trends	Yes	Yes	Yes	Yes	Yes	Yes

Source: Research results.

Notes: Robust standard errors (in brackets) are clustered at municipality (block) level. Child characteristics include sex, and birth order. Mother characteristics include age dummies, married, low and variable dummy for head of household. Month fixed effects are dummy variables for birth months. Municipality fixed effects are dummies for municipality of residence of mother. Year fixed effects is a dummies for birth years. Urban dummy is also included. Singleton status is added as control in models based on the DHS sample.All estimations use sample weights.*Yes* that means that the group of variables is included in the regressions.*** p<0.01, ** p<0.05, * p<0.1.

The results in column (2) show only significant effects for walking activities in the third trimester of gestation. The marginal effect is -1.7 percentage points, which represents about of 2% of the mean rate. Column (5) presents the results for preschool attendance. As can be seen, fetal exposure to temperature increases has significant negative effects in all the trimesters. In magnitude, exposure in the third trimester has the greatest effect. The reduction in the probability of attending preschool for infants who were exposed in the third trimester to one standard deviation higher in temperature is 4.8 percentage points. Given the mean rate of 61%, this implies a reduction of 7.8% in the probability of preschool attendance. The same exposure during the first and second trimester leads to reductions of 1.8 and 1.4%, respectively.

The most striking finding is the increased probability of never school attendance when a child is exposed during the first trimester. The point estimate is 0.0368 with a *p*-value of 0.001. This coefficient implies that a child exposed to one standard deviation higher in temperature increases the likelihood of never school attendance by 27%. We also find that those with similar exposure in the second trimester have to 10% of increase (significant at 5%).

Table 17 explores possibleurban/rural heterogeneities.We find a negative and statistically significant effect of exposure during the third trimester on walking activities in the urban sample. Specifically, the magnitude of increase in walking activities for children who were exposed one standard deviation lower in temperature is 2.5% (significant at the 5%).The same exposure during the first trimester has an insignificant increase of 0.7%.In contrast, we find significant effects during the first trimester in the rural sample.The likelihood of walking activities is reduced by 3.5 percentage points (*p*-value = 0.05) if a child is exposed in utero to one standard deviation higher of temperature.

Table 17. Estimated Impact of Temperature Changes on Parental Investments in Stimulant activities and Schooling by Residence Area in Colombia, 2005 and 2010

	Stimulation activities				Schooling	
	Playing	Walking	Reading	Singing	Preschool attendance	Never went to school
	(1)	(2)	(3)	(4)	(5)	(6)
			Panel A: Urban			
Prenatal exposure during:						
1st trimester	-0.0108	-0.00657	-0.00707	0.0014	-0.0153	0.0386
	[0.00689]	[0.0108]	[0.0112]	[0.00980]	[0.00298]***	[0.00333]***
2st trimester	0.00719	0.00474	0.0166	-0.0072	-0.00624	0.0136
	[0.00529]	[0.0141]	[0.0110]	[0.00871]	[0.00385]	[0.00564]**
3st trimester	-0.00468	-0.0208	0.000576	0.0058	-0.0397	0.00197
	[0.00475]	[0.0100]**	[0.0106]	[0.00953]	[0.00665]***	[0.00587]
Number of observations	8,420	8,420	8,420	8,420	149,682	113,914
			Panel B: Rural			
Prenatal exposure during:						
1st trimester	-0.0196	-0.0315	-0.00421	0.01	0.001	0.0306
	[0.0143]	[0.0165]*	[0.0182]	[0.0179]	[0.00479]	[0.00429]***
2st trimester	0.00522	-0.00103	-0.0181	0.0168	-0.0133	0.00201
	[0.0150]	[0.0164]	[0.0225]	[0.0214]	[0.00453]***	[0.00484]
3st trimester	-0.00117	-0.00893	0.00465	0.0182	-0.0697	-0.00376
	[0.0170]	[0.0184]	[0.0210]	[0.0176]	[0.00628]***	[0.00377]
Number of observations	4,786	4,786	4,786	4,786	122,840	88,267
Child characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Mother characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Month fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Municipality fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Municipality specific time trends	Yes	Yes	Yes	Yes	Yes	Yes

Source: Research results.

Notes: Robust standard errors (in brackets) are clustered at municipality (block) level. Child characteristics include sex, and birth order. Mother characteristics include age dummies, married, low and variable dummy for head of household. Month fixed effects are dummy variables for birth months. Municipality fixed effects are dummies for municipality of residence of mother. Year fixed effects is a dummies for birth years. Singleton status is added as control in models based on the DHS sample. All estimations use sample weights. *Yes* that means that the group of variables is included in the regressions. *** p<0.01, ** p<0.05, * p<0.1.

We also found urban/rural differences in preschool attendance. For urban areas, the marginal effect of exposure during the first trimester is negative and estimated at 2.2% (*p*-value=0.01). This same point estimate is negative and corresponds to a statistically insignificant estimate of 0.2% for rural children. The magnitude of effect of third trimester exposure in rural children is three times the corresponding to urban area. A rural child exposed to temperatures one standard deviation higher has a 15.8% reduction in the likelihood of preschool attendance, while for an urban child the reduction is 5.8%.

The results also show substantial urban/rural differences in the effect of exposure during the first trimester on the likelihood of never school attendance. The effects of a marginal increase in temperature are -38 and -20% for urban and rural children, respectively. The effect of the second trimester is significant only for urban children, with a marginal effect of -13% (*p*-value=0.05).

Table 18 investigates possible heterogeneities by sex. We found a significant negative effect of exposure during the third trimester on walking activities for boys. Specifically, the marginal effect is estimated at -2.3 percentage points with a standard error of 0.1.Relative to the mean rate, this would imply a impact of -2.8%. For girls, the marginal effect is estimated at -1.1%, but is statistically insignificant.

In column (4), we observed some differences for preschool attendance by sex. The marginal effects of exposure during the first trimester are -2.2 and -1.4% for boys and girls, respectively. The marginal effect of exposure during the second trimester is statistically insignificant for boys. By contrast, for girls the marginal effect is significant and estimated at -2%.

Table 18. Estimated Impact of Temperature Changes on Parental Investments in Stimulant activities and Schooling by Sex in Colombia, 2005 and 2010

	Stimulation activities				Schooling	
	Playing	Walking	Reading	Singing	Preschool attendance	Never went to school
	(1)	(2)	(3)	(4)	(5)	(6)
			Panel A: Male			
Prenatal exposure during:						
1st trimester	-0.0113	-0.0141	0.00118	0.0111	-0.0141	0.0351
	[0.00834]	[0.0149]	[0.0150]	[0.0121]	[0.00445]***	[0.00320]***
2st trimester	0.00539	0.0118	-0.00138	-0.0111	-0.00591	0.0144
	[0.00730]	[0.0113]	[0.0158]	[0.0130]	[0.00584]	[0.00547]***
3st trimester	-0.0109	-0.0231	0.00636	0.0107	-0.0553	0.00202
	[0.00841]	[0.0105]**	[0.0105]	[0.0137]	[0.00488]***	[0.00486]
Number of observations	6,759	6,759	6,759	6,759	139,792	102,960
			Panel B: Female			
Prenatal exposure during:						
1st trimester	-0.0122	-0.0151	-0.00929	0.001	-0.00973	0.0374
	[0.0102]	[0.0133]	[0.0167]	[0.0161]	[0.00335]***	[0.00462]***
2st trimester	0.00689	-0.0039	0.00643	0.0034	-0.0129	0.00761
	[0.00802]	[0.0185]	[0.0182]	[0.0159]	[0.00465]***	[0.00580]
3st trimester	-0.000821	-0.009	0.00234	0.0061	-0.0418	-0.00217
	[0.00760]	[0.0122]	[0.0138]	[0.0129]	[0.00803]***	[0.00558]
Number of observations	6,447	6,447	6,447	6,447	132,730	99,221
Child characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Mother characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Month fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Municipality fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Municipality specific time trends	Yes	Yes	Yes	Yes	Yes	Yes

Source: Research results.
Notes: Robust standard errors (in brackets) are clustered at municipality (or block) level. Child characteristics include birth order. Mother characteristics include age dummies, married, low and variable dummy for head of household. Month fixed effects are dummy variables for birth months. Municipality fixed effects are dummies for municipality of residence of mother. Year fixed effects is a dummies for birth years. Urban dummy is also included. Singleton status is added as control in models based on the DHS sample. All estimations use sample weights. *Yes* that means that the group of variables is included in the regressions. *** p<0.01, ** p<0.05, * p<0.1.

For never school attendance, the effect of exposure in the first trimester is of similar magnitude between boys and girls. Specifically, the marginal effect is about

30% (*p*-value = 0.01) for both groups. Exposure in the second trimester has significant effects only for boys, with a marginal effect of 10%.

5.3.RESULTS FOR EDUCATION YEARS AND ILLITERATE

We now look at the effect of prenatal exposure on illiteracy and education years for children between 7 and 9 years old.The minimum school age is 6 years old in Colombia.In normal conditions, a child between 7 and 9 years old should be literate, and have at least one year of education.Importantly, these measures are not ideal for investigating the effects of early temperature conditions on parental investment. Indeed, illiteracy and education years are outcomes, not inputs, and parental control over them is limited. These variables are the result of both time and money parental inputs, but also of other factors such as innate ability which may differ across individuals for multiple reasons.

Panel A in Table 19 shows the results for years of schooling. The first entry in column (1) reveals that children exposed prenatally at higher temperatures in the first trimester have fewer years of education. Specifically, a child who was exposed to temperatures one standard deviation higher has 0.08 less years of education (standard error = 0.025).Relative to the mean, this implies that the years of study are reduced by 4%.We also found that the same exposure during the third trimester results in a 8.6% reduction in years of education. Urban/rural differences are also observed. The marginal effect of exposure during the first trimester is -3.6% for urban children, and -6.1% for rural children.In the third trimester, we observed that the effects are more detrimental to urban children (with a marginal effect of 9% against 6% for rural children).

Table 19. Estimated Impact of Temperature Changes on Schooling years and Illiteracy in Colombia, 2005

	All (1)	Urban (2)	Rural (3)	Boy (4)	Girl (5)
	Panel A: Dependent variable is Years of schooling				
Prenatal exposure during:					
1st trimester	-0.0837	-0.0732	-0.114	-0.065	-0.101
	[0.0253]***	[0.0299]**	[0.0124]***	[0.0301]**	[0.0234]***
2st trimester	0.00761	0.00582	0.0155	0.00283	0.0108
	[0.0158]	[0.0198]	[0.0129]	[0.0165]	[0.0176]
3st trimester	-0.172	-0.197	-0.107	-0.168	-0.177
	[0.0246]***	[0.0280]***	[0.0135]***	[0.0259]***	[0.0247]***
Number of observations	202,181	113,914	88,267	102,960	99,221
	Panel B: Dependent variable is Illiteracy				
Prenatal exposure during:					
1st trimester	0.0174	0.0141	0.0264	0.0196	0.0146
	[0.00252]***	[0.00249]***	[0.00424]***	[0.00379]***	[0.00258]***
2st trimester	-0.000585	-0.00184	0.00391	0.00171	-0.0032
	[0.00294]	[0.00362]	[0.00515]	[0.00394]	[0.00319]
3st trimester	0.00302	0.00311	0.00274	0.00568	0.000384
	[0.00242]	[0.00291]	[0.00391]	[0.00312]*	[0.00279]
Number of observations	202,433	113,966	88,467	103,107	99,326
Child characteristics	Yes	Yes	Yes	Yes	Yes
Mother characteristics	Yes	Yes	Yes	Yes	Yes
Month fixed effects	Yes	Yes	Yes	Yes	Yes
Municipality fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Municipality specific time trends	Yes	Yes	Yes	Yes	Yes

Source: Research results.

Notes: Robust standard errors (in brackets) are clustered at municipality block level. Child characteristics include birth order. Mother characteristics include age dummies, married, low and variable dummy for head of household. Month fixed effects are dummy variables for birth months. Municipality fixed effects are dummies for municipality of residence of mother. Year fixed effects is a dummies for birth years. Urban dummy is also included for models (1), (4) and (5). A dummy for child's sexis included for models (1), (2) and (3). All estimations use sample weights. *Yes* that means that the group of variables is included in the regressions. *** p<0.01, ** p<0.05, * p<0.1.

There are no substantial differences by sex in the effect of early temperature conditions on education years. The marginal effect of exposure during the first trimester is -3.4% for boys, and -5% for girls. In the third trimester, we find marginal effects around -8.4 for boys and girls. These effects are estimated very precisely, being statistically significant at the 1% level.

Panel B (Table 19) shows the results for illiteracy.Temperature changes have statistically significant effects only in the first trimester (Column (1)).The marginal effect is estimated at 1.7 percentage points. Turning to urban/rural comparisons (Columns (2) and (3)),we found that exposure in the first trimester appears to have more detrimental effects on urban children. Specifically, the marginal effect is estimated at 20% for urban children and 12% for rural children. By sex, we found no substantial differences.For boys, we found a marginal effect of 16% (*p*-value = 0.01). The corresponding marginal effect for girls is 15%, which is also significant at the 1% level. In addition, we also found that exposure in the third trimester resulting in significant increases in the probability of illiterate for boys.The point estimate is 0.00568 with a standard error of 0.00312.

5.4.INVESTIGATING REASONS FOR DIFFERENTIAL INVESTMENTS

Our final effort is to present evidence of reasons why early temperature shocks affect parental investment. We investigated two potential links. First, temperature increases above the average could be associated with persistent reductions in economic activity. Second, mothers could change fertility and labor supply if they have less healthy children (BECKER; TOMES, 1976).

We started investigating whether there are persistent economic shocks. Persistent reductions in economic activity would have two potential effects on parental investments. On the one hand, lower labor participation may imply falls in family income.This would negatively affect the financial ability of parents to invest.

In this way, the probability of school attendance could be adversely affected. On the other hand, lower labor force participation could increase parental investment in time-intensive inputs. Miller and Urdinola (2010) show that when the cost of time is low, mothers tend to invest more in child health care.Therefore, persistent declines in the opportunity cost of time could positively affect vaccines and stimulation activities. However, our results suggest that there are other most important mechanisms since investment in these inputs tend to be lower for children who were prenatally exposed to higher temperatures.

To empirically investigate these possibilities, we run all the above specifications but now included as a control variable shocks in the GDP in the year immediately after birth.The results of this exercise are presented in Table 20. Each line in the table represents a separate regression.Columns (1) to (3) represent the effects of exposure from first to third trimester. Column (4) has the coefficient of early GDP shocks.There is virtually no change in the coefficients with prenatal exposure to temperature changes. In fact, the coefficients increase slightly in many cases. Early GDP shocks, in turn, do not appear to be statistically significant in most of the time.This does not necessarily mean that temperature shocks do not affect economic activity.Rather, it means that the effects of temperature on economic activity are not persistent. In any case, controlling for GDP shocks does not change our results. This suggests that changes in value of time are not the main link between temperature shocks and parental investment.

Table 20. Estimated Impact of Temperature Changes on Parental Investments Controlling by Early GDP shocksin Colombia, 2005 and 2010

	Prenatal exposure during:			Early GDP shocks	N
	1st trimester (1)	2st trimester (2)	3st trimester (3)	(4)	(5)
Vaccinations:					
Hepatitis B	-0.00597	-0.0182	0.00891	-0.0165	21,290
	[0.00912]	[0.00677]***	[0.00750]	[0.0122]	
DPT	-0.0100	-0.00236	0.000129	-0.00923	21,238
	[0.00632]	[0.00358]	[0.00567]	[0.00540]*	
Polio	-0.00879	0.00153	-0.00203	0.00308	21,588
	[0.00396]**	[0.00314]	[0.00466]	[0.00562]	
Measles	-0.0108	0.00311	-0.00834	0.00496	19,477
	[0.00412]**	[0.00928]	[0.00627]	[0.00761]	
Nutrition:					
Breastfeeding duration	-0.0248	0.405	-0.0676	-0.792	11,426
	[0.210]	[0.298]	[0.238]	[0.332]**	
Stimulation activities:					
Playing	-0.0154	0.00938	-0.00967	-0.0029	12,139
	[0.00707]**	[0.00526]*	[0.00549]*	[0.0124]	
Walking	-0.0149	0.00657	-0.0205	0.00389	12,139
	[0.00922]	[0.00994]	[0.00869]**	[0.0203]	
Reading	-0.00569	0.00345	-0.00184	-0.0192	12,139
	[0.00920]	[0.0135]	[0.00902]	[0.0210]	
Singing	0.0055	-0.00402	0.00616	-0.00832	12,139
	[0.00969]	[0.00940]	[0.00841]	[0.0170]	
Schooling:					
Preschool attendance	-0.0127	-0.00887	-0.0487	0.00241	263,760
	[0.00295]***	[0.00327]***	[0.00552]***	[0.00435]	
Never went to school	0.039	0.0119	0.00122	0.0021	182,777
	[0.00303]***	[0.00496]**	[0.00514]	[0.00284]	

Source: Research results.

Notes: Robust standard errors (in brackets) are clustered at municipality (or block) level. All child and maternal controls and year, month and municipality fixed effects are included. Urban dummy is also included. All estimations use sample weights. *** p<0.01, ** p<0.05, * p<0.1.

Despite this, two caveats remain. First, our analysis is based on a proxy of local economic activity. It could be argued that there are heterogeneous effects across different specific sectors of the economy. In this case, our analyses would underestimate the importance of early economic shocks. Second, it could also be argued that there is a substantial measurement error in our proxy of economic activity.Again, our analysis would underestimate the effects of changes in economic activity. Given data limitations, we cannot rule out these possibilities.

We now explore how the labor force participation of mothers responds to early temperature conditions. The maternal labor force participation could be affected not only by changes in value of time, but also by the initial endowments of their children. A mother could reduce their labor supply to take care of unhealthy children. Conversely, unhealthy children could increase financing requirements, which would lead to an increase in labor force participation.Panel A of Table 21 presents regressions in which the dependent variable is a binary variable equal to one if the mother participates in the labor market. The results indicate that there are only significant effects for boys in the first trimester, with a marginal effect of 0.6 percentage points. These results suggest that changes in labor force participation are unlikely to play an important role.

It has been well documented that children growing up in larger families receive less investment in human capital due to decreased per capita income(BECKER; LEWIS, 1973). The theoretical model of Becker and Tomes (1976) suggests that families can change their fertility decisions in response to variations in initial endowments.The predictions of this model are ambiguous.On the one hand, less healthy children increase the cost of child quantity.That is if prenatal exposure to high temperature reduces life expectancy, then, it would increase the number of births that a family requires to achieve a given number of surviving children. Then, early temperature shocks would increase the shadow price of child quantity, which lead to a reduction in fertility.On the other hand, unhealthy children mean lower returns of parental investment, which would increase the shadow price of child quality. Under the quantity-quality tradeoff in this model, this would lead to an increase in fertility. In addition, the lower life expectancy of unhealthy children may increase replacement fertility, given constant prices of child quantity and quality (DOEPKE, 2005).

Table 21. Estimated Impact of Temperature Changes on Maternal Labor Supply and Family Sizein Colombia, 2005

	All (1)	Urban (2)	Rural (3)	Boy (4)	Girl (5)
	Panel A: Dependent variable is maternal labor force participation				
Prenatal exposure during:					
1st trimester	0.000812	0.00105	0.000207	0.00645	-0.00478
	[0.00287]	[0.00412]	[0.00229]	[0.00322]**	[0.00398]
2st trimester	0.00458	0.00629	-0.000868	0.00327	0.00574
	[0.00344]	[0.00416]	[0.00228]	[0.00318]	[0.00463]
3st trimester	-0.0016	-0.00137	-0.0018	-0.00411	0.0013
	[0.00190]	[0.00245]	[0.00173]	[0.00293]	[0.00231]
Number of observations	606,500	335,276	271,224	310,268	296,232
	Panel B: Dependent variable is additional children				
Prenatal exposure during:					
1st trimester	-0.00185	-0.000807	-0.00494	-0.00608	0.00269
	[0.00219]	[0.00264]	[0.00325]	[0.00283]**	[0.00420]
2st trimester	0.00378	0.00339	0.00452	0.00479	0.0026
	[0.00233]	[0.00275]	[0.00302]	[0.00391]	[0.00259]
3st trimester	-0.0113	-0.011	-0.0111	-0.0128	-0.00955
	[0.00282]***	[0.00371]***	[0.00243]***	[0.00417]***	[0.00291]***
Number of observations	542,856	300,063	242,793	277,692	265,164
Child characteristics	Yes	Yes	Yes	Yes	Yes
Mother characteristics	Yes	Yes	Yes	Yes	Yes
Month fixed effects	Yes	Yes	Yes	Yes	Yes
Municipality fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Municipality specific time trends	Yes	Yes	Yes	Yes	Yes

Source: Research results.

Notes: Robust standard errors (in brackets) are clustered at municipality block level. Child characteristics include birth order. Mother characteristics include age dummies, married, low and variable dummy for head of household. Month fixed effects are dummy variables for birth months. Municipality fixed effects are dummies for municipality of residence of mother. Year fixed effects is a dummies for birth years. Urban dummy is also included for models (1), (4) and (5). A dummy for child's sex is included for models (1), (2) and (3). All estimations use sample weights. *Yes* that means that the group of variables is included in the regressions. *** p<0.01, ** p<0.05, * p<0.1.

In Panel B of Table 21 we investigated if early temperature conditions affect fertility. For this, we use the subsample of children between two and nine years old and estimate a model where the dependent variable is a dummy indicating if a child has at least one younger brother from the same mother. The intuition is that a child who does not have a younger brother implies that the mother does not increase fertility. The results suggest that exposure in the third trimester reduced the likelihood of having an additional child. The point estimate is between -0.011 and -0.009, being significant in all cases at the 1% level. Relative to the mean, this implies a marginal effect of -2.5%. We also found a negative and significant effect of exposure in the first trimester for the boys. These results suggest that prenatal exposure to temperature shocks leads to reductions in fertility. Thus, this indicates that children exposed prenatally to high temperature are benefited by the reduction in family size. However, this also suggests that there is another mechanism annihilating the benefit of reduced fertility.

CHAPTER 6

DISCUSSION AND FINAL REMARKS

6.1.INTERPRETING THE RESULTS

Analyzing the relationship between weather shocks, initial endowments, and parental investments in human capital has been the main subject of this study.Our findings are divided into two parts.First, we found that exposure to heat waves has adverse consequences on the initial endowments.The most important timing is the first trimester, since we found greater effects. The effects are greater for children of mothers living in rural areas.

The second set of results shows that prenatal exposure to heat waves decreases parental investment in child health care and schooling. In most cases, the most important timing is the first trimester. We found differences by sex and urban/rural status in the effects on parental investment in child health care. Specifically, parental investment in child health care is reduced to a greater extent for boys and urban children. In addition, we found that human capital formation is adversely affected. Indeed, individuals exposed to higher temperatures in utero are more likely to be illiterate and have fewer years of education during childhood.

There are several possible interpretations of these results. The first is that the differential in parental investments between children with fetal exposure to low and high temperature is unrelated to changes in initial endowments, but reflects a persistent reduction in value of time that negatively affected both birth outcomes and parental investments.There is evidence documenting that increases in temperature can negatively affect economic activity, even in non-agricultural sectors, which could reduce wages and/or employment (DELL; JONES; OLKEN, 2012). Since the drop in income is caused by temperature shocks, their omission does not introduce a bias in our estimates per se, but rather affects the interpretation of the estimated relationship.Thus, in the presence of persistent falls in income, the effect of weather shocks on investment in human capital can be attributed not only to variations in initial endowments.But if the persistent fall in income play a key role in explaining our results, then we should see that the parental time-intensive investment increase for children exposed to high temperature in utero as a result of lower value of time, as suggested by the findings ofMiller and Urdinola (2010). In general, the use of health services in Colombia is cheap or free but requires a considerable amount of time.However, we found that parental investment in child care not only not increased, but decreased with prenatal exposure to heat waves. In addition, we also do not find that maternal labor supply decreases, which is not consistent with persistent reductions in value of time. As an exploratory analysis, we examine the relationship between early temperature conditions and parental investment including a proxy variable of shocks in local economic activity to investigate the role of persistent drop in income.All our estimates remain unaffected when we control for such proxy variable.Although we cannot completely rule out the possibility that persistent changes in income play a role, the evidence suggests that they are not the main mechanism explaining our results.

The second interpretation is that what we are finding is a change in the composition of families.It could be argued that a family could mitigate temperature shocks by migrating and families who take these decisions have higher socioeconomic status. Thus, our results may reflect the fact that less educated mothers, on average, are exposed to higher temperature and they tend to invest less in their children regardless of fetal exposure to heat waves. We are skeptical of this given the low migration rates of women during pregnancy. In addition, heat waves could be correlated across space, implying that, to mitigate a temperature shock, a family would have to travel considerable distances, increasing the cost of this strategy.Moreover, our methodology easily overcomes various falsification tests, which suggest that there are no compositional changes in births driving our results.

The third possibility is that, given constant returns to child quality, variations in initial endowments involve externalities in the ability of parents to invest in human capital.Families could increase their labor force participation due to higher financial requirements imposed by unhealthy children.This would negatively affect parental investment in time-intensive inputs.Also, unhealthy children could impose higher medical costs and, given a constant family income, this would imply lower available income to invest in human capital. Although we believe these pathways very plausible, our findings suggest that they are also not the entirety of the story.To start with, our results indicate that exposure to heat waves is correlated with increases in labor force participation for the sample of boys. In addition, we found that families reduce fertility when children are exposed to higher temperatures in utero, which also weighs against the interpretation that our results reflect negative externalities in parental investments.

The fourth possibility is that endowments are positively related to marginal returns of investment and parents invest to the point where the marginal return is equal to marginal cost, as suggested by the model Becker Tomes (1976). Thus, the negative consequences on the initial endowments of fetal exposure to heat waves results in lower return to investment and parents respond by adopting reinforcement strategies.This interpretation is made somewhatmore plausible by the results in the previous studies documenting a positive intrafamily correlation between initial endowments and parental investments,and by our results. In particular, a possible interpretation of our findings is that early temperature shocks impair cognitive abilities and this increases the marginal cost of investment, which, in turn, leads to disincentives to invest in human capital.

Our favorite interpretation is a combination of the third and the fourth. It seems plausible the existence of externalities implied by variations in initial endowments. But we find this is not all that is going on. Rather, early exposure to temperature shocks changed the returns to child quality and families responded by reallocating resources.

6.2.IMPLICATIONS FOR POLICY

Our findings provide evidence suggesting that parents respond to changes in initial endowments. This has implications for studies evaluating the fetal programming hypothesis, which states that chronic diseases in the final stages of life stem from the uterus.For example, an influential work by Almond (2006)found that individual exposed prenatally to pandemic influenza were more likely to report physical illnesses, besides lower educational attainment and wages. However, in the presence of parental response to variations in initial endowments, as our results suggest, parents could exacerbate the initial disadvantages by investing less in human capital. Therefore, part of the effects found in Almond (2006) may reflect the lower parental investment in health care during childhood. Thus, these studies may exaggerate the role of fetal programming and, as a result, its policy implications.

Our results indicate an important channel through which climate change could increase inequality and have lasting effects on the accumulation of human capital. Currently, the cost-effectiveness analyses of policies to mitigate climate change include a broad set of dimensions where climate change could have adverse consequences, but typically do not incorporate the potential indirect effects on human capital accumulation. As a result, such analyses are likely to underestimate the benefits of mitigating climate change.

Our study also has important implications for current education policies in Colombia. Education policies are focused on the population over six years of age. Our results suggest that such policies would benefit if they are accompanied by interventions aiming at to reduce disparities in birth-outcomes since improvements in endowments have positive effects on parental investment in human capital.While there have already been some debate in the international literature on this, we provide the first evidence for Colombia.The effects of programs such as Families in Action could be potentiated if they are accompanied by interventions during the prenatal period. Such prenatal interventions are substantially less expensive to be implemented that postnatal interventions(DOYLE *et al*., 2009).In addition, there is already some evidence for developed countries that prenatal policies are most effective for the accumulation of human capital (CAMPBELL *et al*., 2002). In view of this, countries such as the UK have recently launched a program that provides domiciliary visits by nurses during pregnancy, which has been proven to be successful in the U.S. Such interventions are nonexistent in Colombia and they are necessary to advance in human capital.

6.3.GENERALIZABILITY AND FUTURE RESEARCH

At this point, we should point out that there are various caveats to the validity of our conclusions. First, our estimates represent the effect of the reduced form of prenatal exposure to temperature shocks. This generates alternative interpretations to our findings, and even though they have little empirical support, we cannot completely rule out them. Second, given the multidimensional concept of capabilities, our estimates do not allow us to disentangle what type of initial endowment has more or less influence on parental investment. This could be important in view that parental response to a cognitive shock could be different from a health shock, as hypothesized by Yi *et al* (2014). Our methodology provides only suggestive evidence of the combined effect of these channels. Finally, it is unclear the external validity of our results for countries with different climatic characteristics. For example, the effects of temperature increases on the initial endowments may be different for countries with very low temperatures.In fact, there is evidence based on correlations suggesting that increases in temperature are beneficial to the fetus in these countries(MURRAY *et al*., 2000). Thus, setting aside the issue of generalizability, the fact that weather shocks will become increasingly common implies that understanding the short and long term consequences of temperature variations is an important question *per se*. Therefore, our study is at least a clarion call for future research in this area.

Future research should assess the effects of temperature on investment in human capital in different contexts (eg, cold climate countries). Other measures of parental investment should also be considered. In particular, it would be useful to see if the parents have different treatment in the use of preventive health services.It is also left for future research to investigate the medium-term impact of temperature on other measures of human capital, such as cognitive test scores. Furthermore, future research should use novel identification strategies in order to disentangle possible heterogeneous responses through different dimensions of initial endowments. In addition, an intriguing question is how early temperature shocks affect individual well-being in the long-term.

References

ABERNETHY, L. J.; PALANIAPPAN, M.; COOKE, R. W. I. Quantitative magnetic resonance imaging of the brain in survivors of very low birth weight. **Archives of Disease in Childhood** , v. 87 , n. 4 , p. 279–283, 1 out. 2002.

ADHVARYU, A.; NYSHADHAM, A. Endowments at Birth and Parents' Investments in Children. **The Economic Journal**, 2014.DOI: 10.1111/ecoj.12186

AGAY-SHAY, K. et al. Ambient temperature and congenital heart defects. **Human Reproduction** , v. 28, n. 8, p. 2289-2297, 5 jun. 2013.

AIZER, A.; CUNHA, F. **The Production of Human Capital: Endowments, Investments and Fertility**: NBER Working Paper 18429.Boston, U.S. 2012.

ALMOND, D. Is the 1918 Influenza Pandemic Over? Long-Term Effects of In Utero Influenza Exposure in the Post 1940 U.S. Population. **Journal of Political Economy**, v. 114, n. 4, p. 672–712, 1 ago. 2006.

ALMOND, D.; CHAY, K. Y.; LEE, D. S. The Costs of Low Birth Weight. **The Quarterly Journal of Economics** , v. 120 , n. 3 , p. 1031–1083, 1 ago. 2005.

ALMOND, D.; EDLUND, L.; PALME, M. Chernobyl's Subclinical Legacy: Prenatal Exposure to Radioactive Fallout and School Outcomes in Sweden. **The Quarterly Journal of Economics** , v. 124 , n. 4 , p. 1729–1772, 1 nov. 2009.

ALMOND, D.; MAZUMDER, B. Health Capital and the Prenatal Environment: The Effect of Ramadan Observance during Pregnancy. **American Economic Journal: Applied Economics**, v. 3, n. 4, p. 56–85, 2011.

ALMOND, D.; MAZUMDER, B. Fetal Origins and Parental Responses. **Annual Review of Economics**, v. 5, n. 1, p. 37–56, 1 jan. 2013.

ANDALÓN, M. *et al*. **Weather Shocks and Health at Birth in Colombia**: World Bank. Policy Research Working Paper 7081. Wasington DC. 2014.

ATTANASIO, O. P. *et al*. Children's Schooling and Work in the Presence of a Conditional Cash Transfer Program in Rural Colombia. **Economic Development and Cultural Change**, v. 58, n. 2, p. 181–210, 1 jan. 2010.

ATTANASIO, O. P.; MARO, V. DI; VERA-HERNÁNDEZ, M. Community Nurseries and the Nutritional Status of Poor Children. Evidence from Colombia. **The Economic Journal**, v. 123, n. 571, p. 1025–1058, 2013.

BECKER, G. S.; LEWIS, H. G. On the Interaction between the Quantity and Quality of Children. **Journal of Political Economy**, v. 81, n. 2, p. 81–90, 1 mar. 1973.

BUCKLES, K. S.; HUNGERMAN, D. M. Season of Birth and Later Outcomes: Old Questions, New Answers. **The Review of Economics and Statistics**, v. 95, n. 3, p. 711–724, 1 jul. 2013.

CAMACHO, A. Stress and Birth Weight: Evidence from Terrorist Attacks. **The American Economic Review**, v. 98, n. 2, p. 511–515, 1 may 2008.

CAMACHO, A.; CONOVER, E. Effects of Subsidized Health Insurance on Newborn Health in a Developing Country. **Economic Development and Cultural Change**, v. 61, n. 3, p. 633–658, 1 abr. 2013.

CAMPBELL, F. A. et al. Early Childhood Education: Young Adult Outcomes From the Abecedarian Project. **Applied Developmental Science**, v. 6, n. 1, p. 42–57, 1 jan. 2002.

CRIMMINS, E. M.; FINCH, C. E. Infection, inflammation, height, and longevity. **Proceedings of the National Academy of Sciences of the United States of America** , v. 103 , n. 2 , p. 498–503, 10 jan. 2006.

CUNHA, F.; HECKMAN, J. The Technology of Skill Formation. **American Economic Review**, v. 97, n. 2, p. 31–47, 2007.

CUNHA, F.; HECKMAN, J. J. Formulating, Identifying and Estimating the Technology of Cognitive and Noncognitive Skill Formation. **Journal of Human Resources** , v. 43 , n. 4 , p. 738–782, 21 set. 2008.

CUNHA, F.; HECKMAN, J. J. THE ECONOMICS AND PSYCHOLOGY OF INEQUALITY AND HUMAN DEVELOPMENT. **Journal of the European Economic Association**, v. 7, n. 2-3, p. 320–364, 2009.

CUNHA, F.; HECKMAN, J. J.; SCHENNACH, S. M. Estimating the Technology of Cognitive and Noncognitive Skill Formation. **Econometrica**, v. 78, n. 3, p. 883–931, 2010.

CURRIE, J.; ALMOND, D. Chapter 15 - Human capital development before age five. **Handbook of Labor Economics**. Elsevier, 2011. v. Volume 4,p. 1315–1486.

CURRIE, J.; NEIDELL, M.; SCHMIEDER, J. F. Air pollution and infant health: Lessons from New Jersey. **Journal of Health Economics**, v. 28, n. 3, p. 688–703, may 2009.

CURRIE, J.; ROSSIN-SLATER, M. Weathering the storm: Hurricanes and birth outcomes. **Journal of Health Economics**, v. 32, n. 3, p. 487–503, may 2013.

DATAR, A.; KILBURN, M. R.; LOUGHRAN, D. Endowments and parental investments in infancy and early childhood. **Demography**, v. 47, n. 1, p. 145–162, 2010.

DELL, M.; JONES, B.; OLKEN, B. Temperature Shocks and Economic Growth: Evidence from the Last Half Century. **American Economic Journal: Macroeconomics**, v. 4, p. 66–95, 2012.

DESCHENES, O.; GREENSTONE, M. The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather. **American Economic Review**, v. 97, n. 1, p. 354–385, 2007.

DESCHENES, O.; GREENSTONE, M.; GURYAN, J. Climate Change and Birth Weight. **American Economic Review**, v. 99, n. 2, p. 211–217, 2009.

DOEPKE, M. Child mortality and fertility decline: Does the Barro-Becker model fit the facts? **Journal of Population Economics**, v. 18, n. 2, p. 337–366, 2005.

DOYLE, O. et al. Investing in Early Human Development: Timing and Economic Efficiency. **Economics and human biology**, v. 7, n. 1, p. 1–6, 21 mar. 2009.

EDWARDS, M. J. Congenital defects in guinea pigs. Following induced hyperthermia during gestation. **Archives of pathology**, v. 84, n. 1, p. 42–48, jul. 1967.

ELTER, K. et al. Exposure to low outdoor temperature in the midtrimester is associated with low birth weight. **Australian and New Zealand Journal of Obstetrics and Gynaecology**, v. 44, n. 6, p. 553–557, 2004.

ERIKSSON, J. G. et al. Boys live dangerously in the womb. **American Journal of Human Biology**, v. 22, n. 3, p. 330–335, 2010.

Fundación para la Educación Superior y Desarrollo (FEDESARROLLO). **Composición sectorial del empleo en Colombia**. Bogotá, Colombia.*Report*. 2013.

FIGLIO, D. et al. The Effects of Poor Neonatal Health on Children's Cognitive Development. **American Economic Review**, v. 104, n. 12, p. 3921–3955, 2014.

GERMANWATCH. **Global Climate Risk Index 2012: Who suffers most from extreme weather events? Weather-related loss events in 20010 and 1991-2010**. Bonn, Germany. *Report*. 2011.

HACK, M.; KLEIN, N. K.; TAYLOR, H. G. Long-Term Developmental Outcomes of Low Birth Weight Infants. **The Future of Children**, v. 5, n. 1, p. 176–196, 1 abr. 1995.

HECKMAN, J. J. The economics, technology, and neuroscience of human capability formation. **Proceedings of the National Academy of Sciences** , v. 104 , n. 33 , p. 13250–13255, 14 ago. 2007.

HECKMAN, J. J.; STIXRUD JORA; URZUA, S. The Effects of Cognitive and Noncognitive Abilities on Labor Market Outcomes and Social Behavior. **Journal of Labor Economics**, v. 24, n. 3, p. 411–482, 1 jul. 2006.

HSIN, A. Is Biology Destiny? Birth Weight and Differential Parental Treatment. **Demography**, v. 49, n. 4, p. 1385–1405, 2012.

Intergovernmental Panel on Climate Change(IPCC). **Fourth Assessment Report: Climate Change 2007. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change**. Geneva, Switzerland. 2007.

KRAEMER, S. The fragile male. **BMJ : British Medical Journal**, v. 321, n. 7276, p. 1609–1612, 23 dez. 2000.

LAM, D. A.; MIRON, J. A. The Effects of Temperature on Human Fertility. **Demography**, v. 33, n. 3, p. 291–305, 1 ago. 1996.

LAWLOR, D. A.; LEON, D. A.; SMITH, G. D. The association of ambient outdoor temperature throughout pregnancy and offspring birthweight: findings from the Aberdeen Children of the 1950s cohort. **BJOG: An International Journal of Obstetrics & Gynaecology**, v. 112, n. 5, p. 647–657, 2005.

LEWIS, M.; BENDERSKY, M. Cognitive and Motor Differences Among Low Birth Weight Infants: Impact of Intraventricular Hemorrhage, Medical Risk, and Social Class. **Pediatrics** , v. 83 , n. 2 , p. 187–192, 1 fev. 1989.

MATSUURA, K.; WILLMOTT, C. **Terrestrial Air Temperature and Precipitation: 1900-2010 Gridded Monthly Time Series, Version 3.01**. R*eport.* 2012.

Minesterio de Educación Nacional (MEN). **Revolución Educativa 2002-2010 Acciones y Lecciones**. Bogotá, Colombia. *Report*. 2010.

MILLER, G.; URDINOLA, B. P. Cyclicality, Mortality, and the Value of Time: The Case of Coffee Price Fluctuations and Child Survival in Colombia. **The Journal of Political Economy**, v. 118, n. 1, p. 113–155, fev. 2010.

MURRAY, L. J. et al. Season and Outdoor Ambient Temperature: Effects on Birth Weight. **Obstetrics & Gynecology**, v. 96, n. 5, Part 1, 2000.

OECD. **PISA 2009 Results: What Students Know and Can Do–Student Performance in Reading, Mathematics and Science (Volume I)**. *Report*. 2010.

PARMAN, J. **Childhood Health and Sibling Outcomes: the Shared Burden and Benefit of the 1918 Influenza Pandemic**: NBER WORKING PAPER 19505. Boston, U.S. 2013.

PEREDA, P. C.; MENEZES, T. A. DE; ALVES, D. **Climate Change Impacts on Birth Outcomes in Brazil**: Inter-American Development Bank. Working Paper 495. Wasington DC. 2014.

PEREIRA, M. et al. **Impactos económicos del cambio climático en Colombia**.*Report.* 2014.

PRENTICE, A. M. et al. Energy-sparing adaptations in human pregnancy assessed by whole-body calorimetry. **British Journal of Nutrition**, v. 62, n. 1, p. 5–22, 1989.

ROCHA, R.; SOARES, R. R. Water scarcity and birth outcomes in the Brazilian semiarid. **Journal of Development Economics**, v. 112, n. 0, p. 72–91, jan. 2015.

ROSALES, M. F. **Impact of Early Life Shocks on Human Capital Formation: El Niño Floods in Ecuador**: Inter-American Development Bank. Working Paper 503. Wasington DC. 2014.

ROYER, H. Separated at Girth: US Twin Estimates of the Effects of Birth Weight. **American Economic Journal: Applied Economics**, v. 1, n. 1, p. 49–85, 2009.

SCHULTZ, T. P. **Handbook of Population and Family Economics Volume 1**. Elsevier, 1997. v. 1

STAN, C. et al. Hydration for treatment of preterm labour. **The Cochrane database of systematic reviews**. 2013.DOI: 10.1002/14651858.CD003096.pub2

STRAND, L. B.; BARNETT, A. G.; TONG, S. The influence of season and ambient temperature on birth outcomes: a review of the epidemiological literature. **Environmental Research**, v. 111, n. 3, p. 451–62, abr. 2011.

TUSTIN, K.; GROSS, J.; HAYNE, H. Maternal exposure to first-trimester sunshine is associated with increased birth weight in human infants. **Developmental Psychobiology**, v. 45, n. 4, p. 221–230, 2004.

VAN ZUTPHEN, A. R.; HSU, W.-H.; LIN, S. Extreme winter temperature and birth defects: A population-based case-control study. **Environmental Research**, v. 128, n. 1, p. 1–8, jan. 2014.

VENKATARAMANI, A. S. Early life exposure to malaria and cognition in adulthood: Evidence from Mexico. **Journal of Health Economics**, v. 31, n. 5, p. 767–780, set. 2012.

WADHWA, P. D. et al. The association between prenatal stress and infant birth weight and gestational age at birth: A prospective investigation. **American Journal of Obstetrics and Gynecology**, v. 169, n. 4, p. 858–865, out. 1993.

WELLS, J. C. K.; COLE, T. J. Birth weight and environmental heat load: A between-population analysis. **American Journal of Physical Anthropology**, v. 119, n. 3, p. 276–282, 2002.

YI, J. et al. **Early Health Shocks, Intrahousehold Resource Allocation, and Child Outcomes**: NBER Working Paper 20757. Boston. US. 2014.