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Matías Mrejen

Prenatal environment and health at birth in Brazil: empirical and normative aspects

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Área de Concentração: Economia Social e Sustentabilidade.

Orientadora: Profª. Drª. Danielle Carusi Machado

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À Ana

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RESUMO

Esta tese está composta de três capítulos que constituem ensaios independentes, mas inter-relacionados, sobre a relação entre o ambiente pré-natal e a saúde dos recém-nascidos, com ênfase no cenário brasileiro.

O primeiro capítulo tem como objetivo embasar a discussão sobre por que as condições atravessadas no período gestacional e a saúde ao nascer são relevantes. O ensaio aborda as discusões normativas sobre a relação entre justiça e saúde e destaca a relevância da saúde neonatal. Adicionalmente, são apresentados os modelos teóricos e a evidência empírica que têm justificado o interesse de economistas por entender os determinantes da saúde dos recém-nascidos. O argumento central é que as capacitações de uma pessoa são o resultado de um processo dinâmico ao longo da vida que, segundo a evidência, começa na gestação e é afetado pelas condições do ambiente pré-natal.

O segundo capítulo aborda a relação entre flutuações na atividade econômica e a saúde ao nascer nas capitais estaduais do Brasil. Específicamente, é analisado como variações nas taxas locais de desemprego se relacionam com indicadores de saúde dos recém-nascidos nesses municípios. Segundo os resultados, aumentos na taxa de desemprego na cidade de residência da mãe no trimestre prévio ao nascimento estão associados a aumentos nas chances dos recém-nascidos de mães com menos de 24 anos de idade, de mães com menos de 11 anos de escolaridade e de mães negras ou pardas terem peso muito baixo ao nascer (menos de 1500 gramas). Uma versão do ensaio foi publicada no periódico acadêmico *PLOS ONE*, em co-autoria com a Profª. Drª. Danielle Carusi Machado.

O terceiro capítulo avalia se a exposição à *Tragédia de Mariana* durante a gestação teve impacto na saúde dos recém-nascidos cujas mães residiam nos municípios afetados pelo desastre ambiental. Utilizando um modelo de diferenças em diferenças, foi estimado uma diminuição na idade gestacional ao nascer e um aumento na incidência de nascimentos prematuros (menos de 37 semanas de gestação) entre recém-nascidos de mães residentes em municípios diretamente afetados pela *Tragédia*. Uma versão do trabalho foi publicada no periódico acadêmico *Social Science & Medicine*, em co-autoria com o Prof. Dr. Julian Perelman e a Profª Dr.ª Danielle Carusi Machado.

Palavras-chaves: Economia da saúde; Saúde do recém-nascido; ambiente pré-natal; Brasil.

ABSTRACT

This doctoral thesis consists of three independent, but interrelated, chapters. Each chapter is one essay on the relationship between the prenatal environment and health at birth, with emphasis on the Brazilian context.

The first chapter aims to frame the debate on if, and why, environmental conditions endured in utero and health at birth are relevant. The essay summarizes the discussion on the relationship between justice and health, highlighting the role of health at birth. Additionally, theoretical models and empirical evidence that justify economists' interest in understanding birth outcomes are presented. The main argument is that a person's capabilities are the result of a dynamic, life-long, formation process that, evidence suggests, begins in the womb and is affected by in utero conditions.

The second chapter examines the relationship between fluctuations in economic activity and health at birth in Brazilian state capitals. Specifically, it is analyzed how variations in local unemployment rates are related with birth outcomes in those municipalities. According to the results, increases in the unemployment rate in the city of residence of the mother during the three months before birth are associated with higher odds of being born with very low birthweight (under 1500 grams) among newborns from mothers younger than 24 years old, with less than 11 years of schooling and black or brown. A version of the paper was published in the academic journal *PLOS ONE*, together with professor Danielle Carusi Machado.

The third chapter assesses if in utero exposure to the *Mariana Tragedy*, an environmental disaster, had an impact on birth outcomes of newborns from mothers that resided in affected municipalities. Using a difference-in-differences framework, it was estimated that in utero exposure in municipalities directly affected by the *Tragedy* lead to shorter mean gestational age at birth and a higher incidence of preterm birth (less than 37 weeks of gestational age at birth). A version of the paper was published in the academic journal *Social Science & Medicine*, together with professors Julian Perelman and Danielle Carusi Machado.

Key-words: Health economics; birth outcomes; prenatal environment; Brazil

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LIST OF ABBREVIATIONS AND ACRONYMS

LBW	Low birthweight (birthweight under 2500 grams)
VLBW	Very low birthweight (birthweight under 1500 grams)
PTB	Preterm birth (less than 37 weeks of gestational age at birth)
VPTB	Very preterm birth (less than 32 weeks of gestational age at birth)
SGA	Small for gestational age (birthweight below the 10^{th} percentile for the gestational age)
CI	Confidence interval
OR	Odds ratio
DATASUS	Department of Informatics of the Brazilian Unified Health System
SINASC	System of Information on Live Births of DATASUS
SIM	System of Information on Mortality of DATASUS
IBGE	Brazilian Institute of Geography and Statistics
PNAD	Brazilian National Household Sample Survey
OLS	Ordinary Least Squares
UR	Unemployment Rate
PBF	*Programa Bolsa Família*

CONTENTS

INTRODUCTION

Human well-being is a multidimensional concept. Many different factors contribute to a person's welfare, notably: income, wealth, education, health, happiness and the possibility to participate in societal life. Among those factors, health is of special relevance. In the most evident way, to have a good life, whatever the definition of it that one might hold, it is necessary to have a life in the first place. Moreover, disease, disability and any other factor that lead to poor health are obstacles to the opportunity of enjoying a good life.

Based on similar arguments, Deaton (2013a) attributes a central role to health in his overarching account of the evolution of human well-being. Together with sustained growth in income and wealth, and perhaps more importantly, improvements in human health are a central element of the process of human well-being expansion. Life expectancy has seen continuous improvements in the last century and a half in many developed countries, a process that expanded to most countries worldwide since the mid-20$^{\text{th}}$ century.

Reductions in neonatal, infant and child mortality rates have been a central component of the expansion in life expectancy at birth, mainly in the first stages of that process. Better living conditions, pushed forward by economic growth, improved nutrition and public policies based on scientific knowledge on the mechanisms necessary to prevent the transmission of infectious diseases were the key drivers behind those reductions (DEATON, 2013a).

Recent evidence suggests that health early in life is not only important because it determines the chances of survival into adulthood, but also because it is related with health later in life and the development of abilities and skills (GLUCKMAN; HANSON, et al., 2008; ALMOND; CURRIE; DUQUE, 2018; CONTI; MASON; POUPAKIS, 2019). In that sense, conditions endured since the prenatal period might affect the development of health and other elements of human well-being later in life.

Economists, worried with the formation of human skills and abilities and their economic yields, have directed attention to in utero and early-life conditions (CONTI; HECKMAN, 2013, 2014; ALMOND; CURRIE, 2011a; ALMOND; CURRIE; DUQUE, 2018; CONTI; MASON; POUPAKIS, 2019). Differences in the exposure to shocks during the gestational period have been linked to educational and income inequalities later in life[1] (O'DONNELL; VAN DOORSLAER; VAN OURTI, 2015). It is, therefore, relevant to understand how different shocks endured in utero might affect human health.

[1] The argument here is not that they are the only or even one of the more relevant sources of inequalities. Economic inequalities are to a large extent driven by structural and institutional factors (PIKETTY, 2014; MILANOVIĆ, 2016)

This doctoral thesis aims to analyze the empirical and normative aspects of the relationship between the prenatal environment and health at birth, with emphasis in Brazil. It is composed by three independent, but interrelated, chapters. The first chapter aims to frame the debate on if, and why, environmental conditions endured in utero and health at birth should be considered relevant. The second and third chapters are essays analyzing two different kind of shocks to the environment during the gestational period: fluctuations in economic activity and the *Mariana Tragedy*, an environmental disaster.

The first essay begins by reviewing the discussion on the relationship between justice and health in two different approaches to social justice: John Rawls' theory of justice (and its application to health by Norman Daniels) and the capabilities approach, most saliently proposed by Amartya Sen. Then, the essay summarizes the theoretical models and empirical evidence behind economist's concern with in utero conditions and health at birth. The chapter concludes by claiming that if, as evidence suggests, conditions endured in utero and neonatal health are relevant for human health through the life course, and therefore affect the life prospects that a person has, we should be concerned with them.

The second chapter analyzes if in utero exposure to economic downturns is associated with worsened birth. A version of the paper, written together with Prof. Danielle Carusi Machado, supervisor of this thesis, was published in the academic journal *PLOS ONE* (MREJEN; MACHADO, 2019).

We used birth records from all live singleton births in the 27 Brazilian state capitals between October 2012 and December 2016 and linked them to local unemployment rates according to the mother's residence. We estimated the association between different birth outcomes and the local unemployment rate in the three trimesters before birth using a fixed-effects model and controlling for maternal characteristics. We also estimated the association for different groups of mothers, based on marital status, educational level, age and race. According to the results, a 1 percentage point (p.p.) increase in the local unemployment rate in the trimester before birth is associated with 2.68% higher odds of being born with very low birthweight ($<$ 1500 grams). That result is pushed by the effect among newborns from mothers younger than 24 (6.84% higher odds), from mothers with 11 years of schooling or less (4.77%) and from brown or black mothers (3.87%). The associations among children born from younger, less educated and black or brown mothers are robust to the application of a procedure to control for multiple testing, albeit the results considering the whole sample are not. Taken together, these results suggest that children born from women of low socioeconomic status are more vulnerable to in utero exposure to economic downturns.

The third chapter evaluates if the breakage of a dam containing waste from a mining site in the municipality of Mariana, in the Brazilian state of Minas Gerais, in

2015, an environmental disaster popularly known as the Mariana Tragedy, affected the health of newborns exposed in utero. Most of the paper was realized during a three-months stay as a visiting doctoral student in the National School of Public Health of the NOVA University of Lisbon, under the supervision of Prof. Julian Perelman. A version of the chapter, written together with professors Perelman and Carusi Machado, was published in the journal *Social Science & Medicine* (MREJEN; PERELMAN; MACHADO, 2020).

We used administrative data on birth records and reports on the Mariana Tragedy to identify all births from newborns exposed in utero and the intensity of that exposure, according to the mother's municipality of residence. Using a difference-in-differences framework, we estimated the impact of different intensities of exposure on birth outcomes. We found that being directly exposed in utero to the Tragedy resulted in 1.86 days shorter gestational age and 2.6 percentage points higher incidence of preterm birth (< 37 weeks). We found no impact on birthweight related outcomes. The relationship between in utero exposure to catastrophic events and adverse birth outcomes is usually attributed to heightened maternal stress. However, as the effects we found are larger than in previous studies, we hypothesize that this is probably due to the Tragedy impacting birth outcomes not exclusively through heightened maternal stress, but also through depressed economic activity in directly affected municipalities.

The thesis concludes with a brief discussion of the results presented in the two empirical chapters (i.e., chapters 2 and 3) in the light of the normative, theoretical and empirical relevance of prenatal environment and health at birth discussed in the first chapter.

FIRST ESSAY

1 IN UTERO ENVIRONMENTAL CONDITIONS AND BIRTH OUTCOMES: WHY WE SHOULD CARE

1.1 Introduction

Health is a central element of human flourishing. The ability to live a life that one subjectively values is, to a large extent, determined by health conditions. That importance is recognized in the Sustainable Development Goal 3 of the 2030 Agenda for Sustainable Development: "ensure healthy lives and promote well-being for all at all ages" (UN, 2019).

In recent years, health at birth has garnered wide attention from the biomedical sciences and economics. Low birthweight and prematurity, birth outcomes determined during the gestational period, are linked to higher rates of neonatal mortality and morbidity (BLENCOWE et al., 2019; KATZ et al., 2013). Environmental conditions endured in utero and during the first moments of life are relevant for health during the entire lifespan. The "Developmental Origins of Health and Disease" paradigm has tried to identify the physiological mechanisms through which in utero and early-life conditions can affect adult health and disease (GLUCKMAN; HANSON, et al., 2008; GLUCKMAN; HANSON, 2004). Likewise, economists have developed theoretical models (CONTI; HECKMAN, 2013, 2014; CUNHA; HECKMAN, 2007; HECKMAN, 2007) and found abundant empirical evidence linking in utero conditions with birth outcomes and health, educational achievements and labor market results later in life (ALMOND; CURRIE; DUQUE, 2018; ALMOND; CURRIE, 2011a; CONTI; MASON; POUPAKIS, 2019).

In parallel, normative inquiries on the nature of social justice have devoted attention to health. Different approaches have tried to give an answer to the question of if, and why, health is of special moral importance (ANAND; PETER; SEN, 2004; EYAL et al., 2013; DANIELS, 2008; SEN, 2002; VENKATAPURAM, 2011). However, as those theories focus on humans as moral agents capable of assuming responsibility for their own actions, they have not addressed questions related with health issues ranging from conception to childhood.

This essay aims to answer if, and why, health at birth is relevant from a normative point of view. That is, we aim to give a justification of why we should care about in utero environmental conditions and birth outcomes. To answer that question, we briefly review the literature on social justice applied to health and on the short-term and long-term consequences of conditions endured during the gestational period.

We begin by reviewing the arguments about the relationship between justice and health in two of the most prominent approaches to social justice[1]: Rawls' theory of justice and the capabilities (or capability) approach. We do not intend to thoroughly analyze neither the extensive debates about the relationship between justice and health (ANAND; PETER; SEN, 2004; EYAL et al., 2013) nor the extent of the agreements and disagreements between the two approaches (BRIGHOUSE; ROBEYNS, 2010). Our goal is limited to understanding why health is considered of special relevance in each approach and how that is related with in utero environmental conditions and health at birth.

First, we summarize the main arguments of John Rawls' theory of justice and its application to health by Norman Daniels (DANIELS, 2008, 2013; RAWLS, 2005a,b). Then, we discuss some of the contributions made to the discussion from the capability approach. We discuss Amartya Sen's (SEN, 1980, 2001, 2002, 2004a,b, 2009) critiques to the *Rawlsian* approach to social justice and the central human capabilities identified by Martha Nusbaum (2008). We also review Sridhar Venkatapuram's (2011) notion of capability for health, which considers capability formation as a life course dynamic process. The section ends with a brief discussion on the partial agreement between the two approaches and why in utero environmental conditions and birth outcomes could be relevant.

In the third section, we summarize the role of in utero conditions and birth outcomes in economics. We present Heckman's model of capabilities formation, which underlies economist's interest in the gestational period and early-life, and its applications for understanding the relevance of shocks endured in utero (ALMOND; CURRIE; DUQUE, 2018; CUNHA; HECKMAN, 2007; HECKMAN, 2007; CONTI; HECKMAN, 2014). Subsequently, we review the empirical evidence on the effects of shocks endured in utero on birth outcomes and its possible impacts on health, educational achievements and labor market status later in life. We do not intend to exhaustively review the empirical literature, but to illustrate what is the evidence on the relevance of the prenatal environment and birth outcomes and what kind of shocks endured in the gestational period have been analyzed.

The article concludes with a brief recapitulation of the main arguments. Specifically, we claim that, considering the empirical evidence, in utero environmental conditions and its effects on birth outcomes are relevant from a normative standpoint. If conditions endured in utero and neonatal health are relevant for human health through the life course, and therefore affect the life prospects that a person has, we should be concerned with them.

[1] There is a third prominent approach to social justice, usually referred to as "luck egalitarianism". Contributions from several authors, like Richard Arneson, G. A. Cohen and John Roemer have been grouped under this category (ARNESON, 2004; HAUSMAN, 2013). While there are applications of this approach to health (SEGALL, 2009; TEMKIN, 2013), they are more focused on identifying which health inequalities should be compensated than on providing arguments about if, and why, health has a special moral relevance.

1.2 Justice and health

1.2.1 Justice and health: a *Rawlsian* approach

John Rawls' theory of justice has the objective of finding the principles that should guide the institutional foundations of a society. In societies of free and equal citizens, who may hold profoundly diverse reasonable religious, philosophical and/or moral doctrines, a conception of justice that can be shared, despite those differences, is needed. That conception of justice, passible of being shared by individuals with profound divergences, should be as independent as possible of their conflicting philosophical, religious and moral doctrines (RAWLS, 2005b).

According to Rawls, a society is a cooperative venture for mutual advantage in which individuals have both an identity and a conflict of interests. An identity of interests because social cooperation makes it possible for individuals to have a better life than in their own. Conflict of interests because there are divergences about how to distribute the greater benefits produced by cooperation, of which individuals prefer a larger share in order to pursue their ends. A set of principles of justice that provide rules to assign rights and duties to individuals and define how to distribute the benefits and burdens of social cooperation are needed (RAWLS, 2005a).

Rawls argues that reasonable individuals who hold different philosophical, religious and moral doctrines can still agree that institutions are just when there is no arbitrariness in the distribution of basic rights and duties and in the allocation of the advantages of social life. In that sense, Rawls conception of "justice as fairness" needs principles that are agreed to in a situation completely free from arbitrariness (RAWLS, 2005b).

That non-arbitrary situation is created by Rawls through a thought experiment: a hypothetical situation that he calls the "original position" (RAWLS, 2005a,b). The original position is a situation in which a representative group of rational individuals, under a "veil of ignorance", debate and agree upon what principles of justice should guide the institutional foundations of society. The "veil of ignorance" implies that agents in the original position do not know neither their respective vested interests, nor how they were favored or disfavored by natural chance or by the contingency of social circumstances. Under those conditions, no one is able to design principles to favor his particular conditions and, therefore, the resulting principles of justice can be considered the result of a fair agreement (RAWLS, 2005a).

Under those circumstances, two principles of justice would be chosen. Those principles are guidelines on how the basic institutions of society can realize the values of liberty and equality. The first principle states that everyone has an equal claim to a scheme of equal basic rights and liberties, compatible with the same scheme for all. The second principle states that social and economic inequalities should be attached to positions and

offices open to everyone under conditions of fair equality of opportunity and that they should be to the greatest benefit of the least advantaged members of society (RAWLS, 2005b). When there are conflicting claims, equal personal liberty should be given priority over the second principle (RAWLS, 2005a).

The second principle, related to social and economic inequalities and to distributive decisions, needs a metric for assessing how advantaged or disadvantaged individuals are when compared to each other (RAWLS, 2005a,b). For Rawls, justice is not meant to provide persons with particular ends or, even less, comprehensive conceptions of the good. Justice is also not about ensuring that people succeed in implementing the plans and projects they elected to pursue according to their own conception of the good (MACLEOD, 2010). For that reason, the metric for comparing individuals should be the resources necessary for the exercise and development of their capacity to have, revise and pursue their own conception of the good. Those resources are the "primary goods" (RAWLS, 2005b) or "primary social goods" (RAWLS, 2005a).

Rawls (2005b) provided a list of five basic primary goods that should be used for interpersonal comparisons: (a) basic rights and liberties; (b) freedom of movement and free choice of occupation against a background of diverse opportunities; (c) powers and prerogatives of offices and positions of responsibility in the political and economic institutions; (d) income and wealth; and (e) the social bases of self-respect.

Although health is not a central topic in Rawls' theory, Norman Daniels (1985, 2008, 2013) expanded it and applied it to health. His work aims to answer what he refers to as the "Fundamental Question of justice for health": what do individuals in a democratic society owe each other in the protection and promotion of health[2]? In order to do that, he seeks to provide answers to three "Focal Questions": *i)* What is the moral relevance of health? *ii)* When are health inequalities unjust? *iii)* How is it possible to meet health needs[3] in a fair way when resource constraints do not allow to meet them all?

The answer to the first focal question draws from Rawls' notion of fair equality of opportunity, included in the second principle of justice. If social justice compels us to build institutions that provide equality of opportunity and the space of exercisable opportunities of any given individual depends on his or her health, then health is relevant for any theory of justice worried with equality of opportunity. In relation to that, and as answer to the

[2] Daniels (2008) understands health as the absence of any significant mental or physical pathology that affects normal functioning. There is a large debate about the appropriateness of that definition. The debate revolves mainly on what should be understood as normality and the centrality given to pathology. Silveira (2017) and Venkatapuram (2011) thoroughly summarized those debates.

[3] In Daniels' words: "Health needs are those things we need in order to maintain, restore, or provide functional equivalents (where possible) to normal species functioning (for the appropriate reference class by gender and age)." (DANIELS, 2008, p. 42). Health needs include, among others, medical services and other forms of health care, adequate nutrition, safe living and working conditions, a healthy lifestyle (exercise, rest, etc.), and an adequate distribution of other social determinants of health.

second focal question (i.e., when are health inequalities unjust?), health inequalities that result from an unjust distribution of socially controllable factors that affect population health should be considered unfair. Therefore, there is a societal obligation to distribute socially controllable factors that affect population health in a fair way[4] (DANIELS, 2008).

However, Daniels recognizes that this general principle does not give answers to those cases in which resources constraints do not allow to decide between conflicting claims. In those cases, as an answer to the third focal question, he suggests that decisions made through a fair deliberative process should count as a fair way of resolving those disputes for which general principles do not provide a straightforward answer. We further focus on the answers to the first and second question, as they are the ones relevant for our objective.

To answer the first question (i.e. is health, and therefore all factors that affect it, of special moral importance?), Daniels links health needs to other goals of justice. According to him, the literature on social determinants of health, taken together with studies that show causal impact of social, economic and environmental factors on health, indicates that the health status of individuals is, at least in part, determined by how some goods and services (e.g., education, housing, income, public health measures, health care) are distributed across social groups stratified by race, gender or class. Therefore, the unequal distribution of those "socially controllable factors" results in unjust health inequalities (DANIELS, 2008). According to him, the role of a theory of justice for health should be to identify a just distribution of those controllable factors.

In Rawls original contribution, health was not considered as an object for justice for two different reasons. First, in the original position, it was assumed that all individuals function normally over their lifespan and, therefore, disease and disability were not present as a possibility in the social contract. Secondly, Rawls (2005a) considered health as a "natural asset", as opposed to social goods that can be redistributed (like health care or education)[5]. However, Daniels recognizes that health is, to a substantive extent, socially determined and should, therefore, be an object of justice concerns. He also points out that disease and disability are often portrayed as the result of bad luck and that therefore cannot be considered unfair, but just unfortunate. However, if social factors affect health and its distribution in a population, we must recognize that at least part of health inequalities are unjust[6] (DANIELS, 2008).

[4] In a previous contribution, Daniels (1985) focused exclusively on health care. However, he later acknowledged that health care is just one among an array of socially controllable factors that affect health and its distribution in a population (SILVEIRA, 2017).

[5] Rawls (2005a) argued that the distribution of "natural assets", including health, is arbitrary and its consequences on a person's position in society should be compensated. However, he considered that the distribution of those *assets* could not be determined by the institutional framework of society, and was therefore outside the scope of justice.

[6] An important caveat is that Daniels approach is not worried exclusively with health inequalities. There could be an hypothetical situation in which all groups in a society (however they are defined, by race,

In short, if disease and disability are factors that reduce the range of opportunities of individuals that are not fully healthy, meeting all health needs that allow individuals to function normally is necessary to protect equality of opportunity (DANIELS, 2008, 2013). That means providing not only health care, but also to distribute socially controllable factors that affect population health. As long as health affects the range of opportunities for individuals, protecting people's health is an obligation for any theory of justice that is concerned with equality of opportunity. In Daniels' own words:

> "[...] health is of special moral importance because it contributes to the range of opportunities open to us. Therefore, the socially controllable factors that promote health – medical services, traditional public health, and the distribution of the broader social determinants of health – derive special importance from their contribution to protecting opportunities" (DANIELS, 2008, p. 21).

To answer the second question (i.e., when are health inequalities unjust?), Daniels seeks to identify the factors that determine health and health inequalities. Just stating that protecting health has moral relevance because it protects opportunity is not enough to establish which inequalities in health are unjust. Daniels' approach to this question is that the general principles of justice of Rawls' theory of justice as fairness capture the main social determinants of health. If we consider a distribution of socially controllable factors that affect health guided by Rawls' principles as just, we can decide which health inequalities are unjust: inequalities in health that remain after a fair distribution of socially controllable factors should be considered acceptable or fair (DANIELS, 2008).

Central to Daniels' argument is the fact that social conditions cumulatively experienced during lifetime are a key element in the determination of health status at any moment in life. The literature on the social determinants of health has long established the existence of a gradient in health[7], even in developed countries with universal access to health care (MARMOT, 2013). Even though the dispute over the causal direction of the relationship between health and economic inequality is far from settled (O'DONNELL; VAN DOORSLAER; VAN OURTI, 2015; DEATON, 2013b) and there are still many questions about the mechanisms that rule that relationship, it seems unquestionable that the existence of health inequalities according to race, education or income should be a concern of any egalitarian theory of justice.

gender or class) have a poor health status, but there are policies that would improve the level of health of at least part of the population without harming the others. Daniels argues that those policies that would create health inequalities should be implemented. As he puts it, not doing so would be unfair because: "Failing to promote health in a population, that is, failing to promote normal functioning in it, fails to protect the opportunity or capability of people to function as free and equal citizens" (DANIELS, 2008, p. 14).

[7] A gradient in health indicates that people that are less advantaged from a socioeconomic standpoint (e.g., according to income or educational level) have worse health.

In Daniels' view, however, a systematic account, that goes beyond generic definitions that only state that all avoidable and unnecessary health inequalities are unjust, is necessary (e.g., WHITEHEAD, 1992). In his view, the *Rawlsian* principles of equal basic liberties, equality of opportunity and of allowing inequalities only in those cases where they make the worst-off fare better provide such an account (DANIELS, 2008).

In Rawls' original theory, hypothetical social contractors evaluate alternative institutional arrangements according to an index of "primary social goods", which includes liberty, power, opportunities, income, wealth and the social bases of self-respect (DANIELS, 2008; RAWLS, 2005b).

Daniels argues that, even though health is not considered a social good in Rawls' theory, opportunity is. Therefore, if individuals' opportunities during their lifetime are determined by health, health is important for social justice and fair equality of opportunity relies on a fair distribution of all socially controllable factors that have influence over it. That is, resources should be used not only to counter the opportunity advantages created by the social lottery, but also the opportunity advantages created by health disparities, which, to a large extent, are not the result of a natural lottery, but determined by the social lottery itself. In Daniels' words: "Because the social determinants of health have a clear effect on population health and its distribution, health is not so 'natural' a good after all" (DANIELS, 2008, p. 58).

In that sense, Daniels' extension of Rawls' theory does not require to level all health inequalities among individuals. It only states that justice concerns demand keeping people healthy (i.e., functioning normally) to assure them a normal opportunity range. According to him, the normal opportunity range can be understood as "the array of life plans reasonable persons are likely to develop for themselves" (DANIELS, 2008, p. 43). He acknowledges that, in any given society, the normal range depends on its historical and technological development, cultural facts and material wealth. Therefore, the normal opportunity range consists of the array of life plans that a reasonable person could expect to follow by virtue of living in a specific society.

According to Daniels, his conceptualization demands both institutions aimed to prevent departures from the normal functioning (which includes institutions that provide for public health, environmental cleanliness, preventive medical services, food and drug protection, nutrition education, among others) and institutions that correct for them (like medical or rehabilitative services) or that keep people as close as possible to normal functioning (like social support services for the chronically ill or disabled).

1.2.2 Capabilities and health

According to Amartya Sen (2009), the capabilities approach diverges from Rawls's theory of justice in two senses: in the ultimate goal ascribed to inquiries about justice and in the appropriate metric to judge the fairness of alternative distributive arrangements. The divergence about the goals of a theory of justice have roots in longstanding different lines of reasoning about justice. Rawls's theory can be seen as an example of what Sen calls "transcendental institutionalism", an approach focused on trying to identify the ideal institutional arrangement that makes a just society. The capabilities approach is part of what Sen calls "realization-focused comparisons", worried with analyzing existing, or at least feasible, alternatives in terms of how just they are when compared to each other.

Rawls' theory of justice is part of a strand of *contractarian* theories that inquire what would be the basic institutions of an ideally just society if free and reasonable individuals were able to make a social contract to choose them. Sen (2009) argues that the problem with that strategy is that there are many different competing principles of justice that could survive critical scrutiny in the hypothetical situation of free, equal and reasonable individuals debating about an ideally just society. In that sense, it does not seem plausible to argue that individuals in the "original position", even under the "veil of ignorance", would arrive to an agreement about what principles would be necessary to construct fair institutions.

Additionally, Sen states that the task of identifying an ideal society that is perfectly just is not necessarily useful for comparing the justness of different existing alternatives. There are many dimensions that make a society just, and it would be impossible, or at least not exempt from arbitrariness, to rank different existing alternatives according to how close they are to the ideal model (SEN, 2009).

In contrast to transcendental theories, comparative analysis, including the capabilities approach, are concerned with social realizations that result from actual institutions and human behavior. In that sense, the capabilities approach seeks to provide elements that contribute to an agreement based on public reasoning on how to rank different feasible alternatives when making choices or judgements about public policies or institutional arrangements in terms of how just are they when compared to each other (SEN, 2009).

The divergence in the appropriate metric to judge the fairness of alternative distributive arrangements is related to disagreements on what should be the object of distributive justice. Sen (1980, 2009) argues that any theory of justice chooses an informational focus: it has to decide what features of the world are deemed relevant to assess a societal arrangement in terms of how just it is, and it also needs a measure to compare an individual's advantage in comparison to others. For example, utilitarianism

concentrates on individual happiness or pleasure, while Rawls based the informational focus of his theory on the distribution of the social primary goods.

According to Sen, the root of that divergence is that the capabilities approach is ultimately concerned with the lives that people can actually live, and it is, therefore, a notion of justice based on accomplishments and not means. He argues that what is important are experiences and realizations of individuals, which cannot be replaced by information about institutions that exist and their rules. That is not to say that institutions and rules are unimportant, but judgements about justice should go beyond the organizational framework of society and include the lives of people. We should be concerned not only in the things that people succeed in doing, but also in the freedoms that they have to choose between different kinds of lives. That freedom of choosing which life we want to live is important both because it is an element of individual well-being and because we may value the process of choice itself (SEN, 2004a, 2009).

The capability approach is not based on utility or resources, but in substantive freedoms. Its concern with substantive freedoms is reflected in the two central concepts coined by Sen: *capabilities* and *functionings*. Functionings are things that a person can do or be, while capabilities are sets of functionings that a person could achieve. Capabilities provide information about all functionings within a person's reach. They are both in the same informational space, but capabilities are a broader concept, as a capability set represent various alternative combinations of functionings among which a person can choose (SEN, 2009).

The concept of capability can be thought of as a set of vectors of functionings that reflect the person's freedom to lead one type of life or another. Capability sets are not directly observable. According to Sen, the capability approach allows to make evaluations of an individual's situation both in terms of the realized functionings (what the person is actually able to do or be) and of the capability set (the real freedoms he or she has to attain those functionings) (SEN, 2004a). From a normative point of view, capabilities are more interesting, and they are informationally more inclusive, because capabilities incorporate both actual and potential functionings (SEN, 2001). However, it is empirically frequently easier to make assessments in terms of functionings (RUGER, 2010; SEN, 2004b).

Capability is related to well-being in two ways. First, if a set of functionings (for example, the ability to walk unaided) is constitutive of a person's well-being, the capability to accomplish those functionings is the person's freedom to achieve well-being. Second, the capability to exercise freedom can itself be valuable. In that sense, we can think about two relevant freedoms. Freedom for individual well-being is the freedom to achieve things that are constitutive of a person's individual well-being. Agency freedom is related to objectives that go beyond individual well-being: objectives related to social or moral values that a person pursues because of a sense of responsibility (SEN, 2009).

In relation to that, to assess a person's well-being based on capabilities it is important to consider two distinctions: the difference between agency and well-being, and the distinction between freedom and achievement. Agency incorporates all possible goals that an individual might have, including the ones that are not related with advancing his own well-being. The difference between achievement and freedom is that between functionings and capabilities. Considering those distinctions, there are four different concepts of individual advantage in the capability approach: (1) "well-being achievement"; (2) "agency achievement"; (3) "well-being freedom"; and (4) "agency freedom" (SEN, 2009). The capability approach allows to make judgements about distributive situations with these four different criteria.

The idea of capability refers to a person's ability to do the different things that he or she values doing. In that sense, the capability approach is focused on human lives and not on resources. Resources should be considered means that a person possesses to be or to do things that he or she ascribes value to. Distributional equity should not be focused on the distribution of those means, but on the distribution of the real opportunities to choose ways of life that people subjectively value. The distribution of resources plays a role in that, but other factors like individual abilities and societal constraints are also relevant.

A crucial element of the divergence between the capability approach and approaches based on resources, like Rawls's, is that different people can have different opportunities for converting income or other goods into things they value. Different kinds of contingencies determine the heterogeneity in the ability to convert income and other goods into things that people subjectively value in their life. People are diverse in many dimensions that affect what they can do with resources (for example, age, gender, disabilities, proneness to illness). Also, people live in different physical environments (for example, climate conditions, pollution), that can affect how they can convert those resources into functionings they value. The individual conversion of resources into functionings is additionally influenced by social conditions, like public healthcare and public educational institutions, or the prevalence of crime and violence and epidemiological characteristics of the place where they live. Finally, cultural factors, like established patterns of behavior in a community, can also affect the need of resources for achieving the same level of a functioning in different places.

Additionally, there are limitations with the perspective, followed by utilitarians, of limiting assessments of the well-being of people to their own judgements about happiness states. The utilitarian framework omits freedom and achievements that do not reflect in the utility space. Additionally, it has limitations when measuring an individual condition in situations of persistent deprivation (RUGER, 2010; SEN, 2009).

The conceptual contrast between "internal" views of health, based on a person's own perception, and "external" views, based on the judgement by healthcare specialists, serves

as an example of that limitation. Basing judgements about someone's health exclusively in his or her internal view might be misleading. For example, a person might adapt to symptoms or health impairments and see them as normal if they are widespread in his or her community. According to Sen, both views are valuable and should be seen as complements and not substitutes. The internal view is central because if someone feels pain or impairments, then that is relevant independently of the judgement of experts. However, the external view is also central because subjective judgements might reflect the adaptation to adverse conditions (SEN, 2004b).

Sen does not predetermine a list of which capabilities and functionings are essential, neither does he establish relative weights for making allocative decisions. According to him, a societal reasoned consensus is necessary for the selection and weighting of different functionings and capabilities, and those agreements would always be local and have contingent validity (RUGER, 2010; SEN, 2009).

For Sen, not giving a list of capabilities is justified by many reasons. One is that it would entail giving a specification of what constitutes a good life, which is contrary to the individual and collective self-determination that is in the roots of the capability approach. Also, even when there is some form of agreement through public reasoning, it is not reasonable to expect achieving a full agreement on a complete and ordered list. However, throughout his writings he has identified some basic capabilities that seem reasonable to assume that are universal, like capability for mobility, to live a life free from disease, to be properly nourished and sheltered and to participate in the social life of the community (SEN, 2002; VENKATAPURAM, 2011).

In that sense, it can be said that the capabilities approach is incompletely specified (RUGER, 2010): it specifies only a basic set of capabilities that can be thought of as universally accepted objectives, and leaves further valuable capabilities unspecified and to be determined by social consensus. The approach does not either predetermine an ordering of valuable functionings and capabilities: the selection and weighting of capabilities is a process that is based on partial agreements that lead to the contingent acceptance of social arrangements, policies or programs (RUGER, 2010; SEN, 2009).

The other major contributor to the capability approach, Martha Nussbaum, agrees with Sen that capabilities are the appropriate measure of quality of life and inequalities across individuals. However, her account does include a comprehensive list of core capabilities that should be universally respected, at least at a minimum threshold. She identified ten central human capabilities that should be guaranteed by every society to every citizen (NUSSBAUM, 2008).

Nussbaum argues that a minimum threshold of the central capabilities should be ensured to every person to allow them to pursue the conception of life they value. In absence of those minimum thresholds, individuals face barriers to pursue what they

consider a worthy life and, therefore, their human dignity is not respected (NUSSBAUM, 2008; VENKATAPURAM, 2011).

Nussbaum seeks to define components of a life that reflects equal human dignity, conceived as being able to be and do certain things (i.e., having certain capabilities) (NUSSBAUM, 2008; VENKATAPURAM, 2011). She identified ten basic capabilities that constitute a life worthy of human dignity: (1) being able to live a life of normal length; (2) being able to have good health; (3) being able to maintain bodily integrity, free from assault or danger; (4) being able to use senses, imagination and think; (5) being able to have emotional attachment to things and people outside ourselves; (6) being able to have a conception of the good and to critically reflect about the goals of one's life; (7) being able to have social affiliations and engage in social interactions without discrimination; (8) being able to express concerns for other species; (9) being able to enjoy recreational activities; (10) being able to participate in political choices that affect one's life and to have effective property rights on an equal basis with others (NUSSBAUM, 2008).

Nussbaum's list of basic capabilities and the principle of a necessary minimum threshold fill in one of the critiques that Sen's approach has received; namely, that he does not propose a rule on how the object of justice (i.e., capabilities) should be distributed (POGGE, 2010). Elizabeth Anderson (1999, 2010) makes a *sufficientarian* argument similar to Nussbaum's. She defends the idea that all citizens in a democratic society have a claim to a capability set sufficient to enable them to function as equals in society. That set should include adequate physical safety, health and nutrition, education, mobility and communication, and the ability to interact with each other.

The central capabilities identified by Nussbaum (2008) and Anderson (2010) signal the importance of health for the capability approach. Amartya Sen (2002) also highlighted that relevance, arguing that health capability is linked with other capabilities. Jennifer Prah Ruger (2010) and Sridhar Venkatapuram (2011) made articulated arguments in defense of the centrality of health in the capability approach.

Ruger (2010) focuses her analysis on justice in health policy and argues that it should be evaluated in terms of health capabilities, rather than health achievements alone. According to her, some health capabilities are more central than others. Namely, the capability to avoid premature death and the capability to avoid escapable morbidity. The two central health capabilities are prerequisites for other health capabilities and other capabilities, like developing abilities, using talents and carrying out plans.

Additionally, she argues that, when thinking about those central health capabilities, we cannot demand complete equality. Instead, we should aim for a hybrid of sufficiency and priority principles. Sufficiency should apply to health capability thresholds as goals, and priority should apply to triage (i.e., how to make distributive decisions) in achieving these goals. She proposes "shortfall equality" as the methodology to make distributive

decisions. Shortfall equality can be thought of as opposed to "attainment equality". While attainment equality compares individuals according to absolute levels of achievement, shortfall equality compares how short of the optimal average falls the actual achievement. For example, shortfall from what is considered medically desirable or expected under normal conditions (RUGER, 2010).

In that process, nobody should be asked to sacrifice their own central health capabilities for the sake of someone else. However, the sacrifice of non-central health capabilities can be demanded in face of scarce resources to prioritize promoting central health capabilities. For example, policies to enhance the capability of a person to avoid premature mortality should be prioritized over efforts to enhance the capability of people to be fitter or to look better. The selection and valuation of other, non-central or non health related, capabilities should be left open to be selected and weighted through collective public deliberation (RUGER, 2010).

The difference between health capabilities and health functionings is the difference between achievements in health and the substantive freedom to choose and attain achievements. However, capabilities are frequently not directly observable or measurable. As functionings or achievements are contained by capabilities, Ruger (2010) argues that health functionings can be used as a proxy of the underlying health capabilities.

Sridhar Venkatapuram argues that the health of a person should be understood as "the ability to achieve a basic cluster of beings and doings -having the capability to achieve a set of inter-related capabilities and functionings" (VENKATAPURAM, 2011, p. 63). In that sense, health is not defined by achievements of certain basic functionings, but by the capability to attain certain capabilities and functionings. Though, empirically, it is frequently only possible to measure actual outcomes (i.e., functionings).

That view of health, Venkatapuram argues, is analogous to considering it a "meta capability": the capability to achieve a cluster of basic capabilities to be and do things that reflect a life worthy of equal human dignity. In his own words, the capability for health is "a meta-capability to achieve a cluster of central human capabilities and functionings each at a threshold level that is commensurate with equal dignity worthy of the human being living in the contemporary world" (VENKATAPURAM, 2011, p. 136). According to him, that cluster of central capabilities are the ten central human capabilities identified by Nussbaum.

The ten central human capabilities identified by Nussbaum (2008) are a decent social minimum of entitlements for a fully human life. In that sense, the capability for health is a source of moral claims for human beings in all places; it is a conception of a human right to the capability to be healthy (VENKATAPURAM, 2011). According to Venkatapuram (2011), a person that has all the ten central human capabilities above a certain threshold level has a fully human life. That means, they have a life with a

sufficient level of opportunity for achieving reasonable and diverse conceptions of the good life, according to their own conceptions of what that is. Every person has claims to social support based on shortages in those capabilities, which affect humann dignity. Those capabilities are moral entitlements that should be previous to any kind of political agreement on the institutional basis of society.

The capability to be healthy is the result of the interaction between a person's biological endowments and needs, external physical and social conditions and individual agency and conversion skills.

Different factors are relevant for ensuring the capability for health. Healthcare, early infant care and stimulation, safe working and housing conditions, community cohesion, income inequality and exposure to environmental hazards, among other factors, affect health conditions and, therefore, are relevant for the capability for health. To ensure that individuals can live their full lifespans and avoid preventable disease-related impairments, those social determinants should be regulated. In that sense, the entitlement to each capability should be understood as the entitlement to the social bases of each causal component of the capabilities, at least to the point of attaining the minimum threshold. In the case of the capability for health, that should be done through intervention into personal features/needs, conversion skills, external physical conditions and surrounding social conditions (VENKATAPURAM, 2011).

According to Venkatapuram (2011), the capability for health, as every other capability, is a cluster of iterative capabilities and functionings. The simplistic picture of a capability as being an isolated opportunity of achieving a chosen functioning neglects the complex process underlying capabilities and functionings. An individual's capability for health, as well as the central human capabilities, should be understood as a dynamic and iterative system made up of four causal components: individual endowments, conversion skills, existing physical conditions and surrounding social conditions. At any given moment during the life course, they are being shaped by dynamic processes underlying each causal component. Processes occurring at various levels, ranging from biological processes within the person to political and economic processes at the national and global level, influence the capabilities of individuals.

In summary, an individual's health capability is created, partially, through social relations and is vulnerable to social phenomena. In that sense, the capability for health captures how social conditions, which affect the access to material resources and individual experiences, influence the ability of individuals to carry out certain activities (VENKATAPURAM, 2011).

1.2.3 In utero environmental conditions and neonatal health: could they be relevant?

The space defined by what Daniels (2008) calls the opportunity range is analogous to the capability space defined by Sen (2001). While Rawls' fair equality of opportunity was relative to jobs and offices, Daniels broadened it to a fair equality of opportunity to pursue a normal opportunity range of life plans. If society has an obligation to provide the resources of equality of opportunity, and health is related with opportunities to pursue life plans one considers valuable, societal action to distribute all socially controllable factors that affect health are needed (DANIELS, 2008; VENKATAPURAM, 2011).

The normal opportunity range refers to the "set of life plans people can reasonably adopt, given their talents and skills" (DANIELS, 2008, p. 63), which is analogous to what Sen (2001) calls a capability set. According to Daniels, we can think of two versions of the capability approach. A strictly egalitarian one, that seems to defend any intervention that erases differences in opportunities produced by inequalities in capability sets, and a less strict version focused on sufficiency of the capability sets.

As reviewed above, most applications of the capability approach to health belong to the second version and, therefore, converge with Daniels' theory (NUSSBAUM, 2008; RUGER, 2010; VENKATAPURAM, 2011). In that sense, what Daniels (2008) calls "a fair share of the normal opportunity range" is analogous to an adequate or sufficient capability set.

Venkatapuram (2011) partially disagrees with the extent of that convergence. According to him, Daniels still considers an individual's talents and skills as given (as the result of a natural lottery), while the capability approach applied to health implies that we should also be concerned on how those talents and skills are formed. In his view, different processes, that range from physiological to political and economic processes, affect the formation of capabilities in a dynamic way. In that sense, we should be worried with the dynamic process that determines the formation of a capability for health and other basic capabilities.

In spite of those partial disagreements, both approaches agree that societal action is needed to affect the distribution of the determinants of health, insofar as they affect the effective opportunities that individuals have to make choices coherent with the life plans they subjectively value. In that sense, both approaches assume mature agents capable of assuming responsibility for the ends they consider relevant and for the means they use. For that reason, the interests of children are not straightforwardly taken into account, as they are not considered to be mature moral agents (MACLEOD, 2010).

Nussbaum (2008) recognized this problem and stated that, when assessing the individual situation of children, functionings, and not capabilities, should be considered

the appropriate metric. In the same line of reasoning, Anderson (2010) stated that actual levels of functionings achieved by children have a profound impact on their capabilities as adults and, therefore, persons must enjoy levels of functionings as children compatible with developing basic capabilities as adults. That is coherent with Venkatapuram's (2011) idea of a dynamic process of formation of capabilities across all moments of a life course.

The same line of reasoning could be extended to the gestational period. If conditions endured in utero and neonatal health are relevant for human health through the life course, and therefore affect the life prospects that a person has, we should be concerned with them[8]. In that case, we would have normative arguments to direct our attention to factors that affect early-life health. For that reason, in the next section, a review of the theoretical and empirical arguments that show the relevance of in utero conditions and neonatal health is presented.

1.3 In utero environmental conditions and birth outcomes in economics

1.3.1 A model of capabilities formation

Economists' interest in health stems from its relevance for the development of human capital (ALMOND; CURRIE, 2011b). Human capital can be understood as an intangible stock of knowledge, skills, and other attributes that can produce economic returns during the lifetime of an individual (CONTI; MASON; POUPAKIS, 2019). If health is one of those attributes, understanding how it is developed should be of interest for economists.

Michael Grossman (1972, 2000) presented a pioneering model of human health production. In his model, health can be thought of as a health capital stock that individuals are endowed with at any point in time and provides direct utility to them. Ageing causes deterioration of health through time and investments (for example, medical care) is needed to maintain it.

Equation 1.1 presents a simple form of Grossman model of human health production (CONTI; MASON; POUPAKIS, 2019; GROSSMAN, 2000):

$$H_{t+1} = (1 - \delta_t)H_t + I(M_t + T_t + E) \tag{1.1}$$

Where H represents the health stock, t represents a time period, and δ is the deterioration rate of health. Investments (I) are a function of expenditure (M) and time (T) spent in medical care (or other health enhancing inputs). Education (E) is assumed

[8] That concern is independent of the conception one holds about the status of fetuses as moral persons.

to improve productivity of those investments. Health capital stock affects an individual's utility level both directly (i.e., as consumption) and through labor market productivity and income (i.e., as investment).

A relevant aspect of this model is its linearity. The health stock at any given period enters separately from the investment function. That implies assuming that investments are equally effective at all levels of initial health (i.e., health stock) (CONTI; MASON; POUPAKIS, 2019). Additionally, depreciation of health capital implies that the effect of any shocks, even those endured during early life, fades out over time. So, at any point in time, events further in the past will be less important than more recent events (ALMOND; CURRIE, 2011a). While those implications can be appropriate for studying health during adulthood, they are not coherent with empirical evidence on the process of health development in early life. According to that evidence, health and investments in utero and in early childhood have sustained effects on adult outcomes (ALMOND; CURRIE; DUQUE, 2018; ALMOND; CURRIE, 2011a,b; CONTI; MASON; POUPAKIS, 2019).

Cunha and Heckman (2007) provided a model coherent with the developmental perspective (i.e., based on the life cycle) on health and disease. While their initial model was focused on the formation of cognitive and non-cognitive skills, Heckman (2007) introduced health into what he called a "model of capability formation". In his model, capability formation can be thought of as a dynamic, life cycle, process that starts in utero and continues during childhood and adolescence, and affects a variety of adult outcomes, including health (HECKMAN, 2007; CONTI; HECKMAN, 2013, 2014).

It is worth noting that Heckman's notion of capabilities is not exactly the same one as in the capabilities approach. According to him, "capabilities are the capacities to function effectively in economic and social life" (CONTI; HECKMAN, 2013, p. S135). In that sense, his view is more focused on the instrumental aspects of human skills and abilities, which are related to well-being across the life cycle (CONTI; HECKMAN, 2014). The emphasis put by Sen (2009) on agency freedom, which can be related with goals that go beyond individual well-being (i.e., objectives related to social or moral values), does not play a role in Heckman's theory. However, the partial convergence between the approaches, even more considering the notion of a dynamic process of capabilities formation in which health plays a crucial role (VENKATAPURAM, 2011), is interesting.

In Heckman's model of capabilities formation, we can think of the capability of a child as a vector of specific capabilities (HECKMAN, 2007; CONTI; HECKMAN, 2014):

$$\theta_t = (\theta_t^C, \theta_t^N, \theta_t^H) \tag{1.2}$$

Where θ_t is the vector of capabilities of the child in the period t, and is composed by cognitive skills (C), non-cognitive skills (N), and health capabilities (H). The technology

of capability formation can be expressed as (CONTI; HECKMAN, 2014):

$$\theta_{t+1} = f_t(\theta_t, I_t, h_t, \theta_t^P) \tag{1.3}$$

The stock of capabilities at any given period $t+1$ (θ_{t+1}) is a function of capabilities (θ_t), investments (I_t), the environment (h_t) and parental traits (θ_t^P) in the previous period. Here, investments can be interpreted broadly, and include investments by parents, schools and public interventions. The model can be written in recursive form. If parental traits are considered fixed in time, the vector of capabilities would be, at any period $t+1$, a function of parental traits (θ^P), an initial capabilities endowment (θ_0) (for example, health during the prenatal period), and all past investments ($I_1, \ldots, I_t$) and environments ($h_1, \ldots, h_t$) (HECKMAN, 2007; CONTI; HECKMAN, 2014).

The production function $f_t(\cdot)$ should have two characteristics that represent the dynamic process of capability formation: dynamic complementarity and self-productivity (CUNHA; HECKMAN, 2007; HECKMAN, 2007; CONTI; HECKMAN, 2014). Self-productivity arises when higher level of capabilities in one period lead to higher level of capabilities in the next period, i.e., when $\frac{\partial f_t(\theta_t, I_t, h_t, \theta_t^P)}{\partial \theta_t} > 0$. This is valid for the same capability (health begets health, cognitive ability begets cognitive ability), as well as between capabilities (for example, a healthy child learns more and will therefore have greater cognitive ability).

Dynamic complementarity arises when capabilities produced at one stage of the life cycle make investments in subsequent periods more productive, i.e., when $\frac{\partial^2 f_t(\theta_t, I_t, h_t, \theta_t^P)}{\partial \theta_t \partial I'_t} > 0$. This implies that investments in capabilities at different stages of childhood are synergistic: high initial investments improve capabilities at later periods, which in turn increases the productivity of later investments. Additionally, later investments increase the impact of early childhood interventions. Taken together, "dynamic complementarity and self-productivity produce multiplier effects which are the mechanisms through which capabilities beget capabilities" (HECKMAN, 2007, p. 13253). Additionally, they show that, in the absence of interventions, inequalities present at birth can get under the skin and propagate throughout childhood and have persistent effects into adulthood (CONTI; HECKMAN, 2014).

A relevant implication of the model is that it blurs the nature versus nurture distinction. In that sense, it is a model that incorporates insights from the biomedical sciences and the empirical literature on the formation of human skills that show that the distinction between innate and acquired characteristics (e.g., health or skills) is not completely sharp (HECKMAN, 2007).

Heckman (2007) and Cunha and Heckman (2007) suggested that a constant elasticity of substitution (CES) production function is a general technology that can capture those characteristics in a two-periods model of capabilities formation during childhood. Almond

and Currie (2011a,b) adapted the model to explain the relevance of in utero environmental conditions and neonatal health. A version of the model, considering a prenatal and an early childhood period is (ALMOND; CURRIE; DUQUE, 2018):

$$H = A\left[\gamma\left(\bar{I_1} + \mu_{1g}\right)^{\Phi} + (1-\gamma)\left(I_2 + \mu_{2g}\right)^{\Phi}\right]^{\frac{1}{\Phi}} \tag{1.4}$$

Where H is health (or other capability-related variable) later in life, A represents factor productivity (which can be related to parental traits), $\bar{I_1}$ and I_2 are the investments made during the first and second period. Investments can be parental investments, but also other investments that can be identified at the level of the individual child. The periods can be defined arbitrarily, but to make the argument clear we can define period 1 as the gestational period and period 2 as early childhood. Investments in period 1 are considered fixed (therefore the bar superscript), but later investments can be responsive. There can be exogenous shocks μ_{1g} and μ_{2g} to investments at any period. The g subscript indicates that those shocks appear at the group level. The parameter γ, where $\gamma \in [0, 1]$, represents the weight of each period in the production of health later in life.

The parameter Φ, where $\Phi \in (-\infty, 1]$, represents the degree of complementarity or substitutability between the investments in different periods. When $\Phi = 1$, investments in the two periods are perfect substitutes. In the opposite case, they are perfectly complementary. The values of Φ and γ are relevant to model and understand how would parental investments in early childhood react to shocks endured in utero (μ_{1g}) by their child or how effective remediation policies (μ_{2g}) could be (ALMOND; CURRIE, 2011a; ALMOND; CURRIE; DUQUE, 2018). Empirically, those two questions can be thought of as the estimation of $\frac{\delta I_2}{\delta \mu_{1g}}$ and $\frac{\frac{\delta h}{\delta \mu_{2g}}}{\frac{\delta h}{\delta \mu_{1g}}}$, respectively.

While this simplified version does not model dynamic complementarity[9] and self-productivity, it helps to shed light on the effect that in utero conditions might have on neonatal health and other results later in life. In other words, it sheds light on the effect on health of shocks endured in utero (i.e., $\frac{\delta H}{\delta \mu_{1g}}$). Almond and Currie (2011a) show that when investments in the two periods are not perfect substitutes (i.e., when $\Phi < 1$), shocks experienced at different baseline levels of investments ($\bar{I_1}$) will have heterogeneous effects on H. All things equal, those with higher levels of parental investments will experience softer effects in H.

Altogether, the model depicts capability formation as a dynamic process that begins in the womb and can affect a variety of adult outcomes (HECKMAN, 2007; CONTI; HECKMAN, 2013). In that process, in utero conditions are important because they can affect neonatal health, and through it outcomes later in life, and because they can have

[9] Almond, Currie, and Duque (2018) summarize the existing empirical evidence and show that, while it is still very scarce, it suggests that dynamic complementarity might not be as strong as implied by Heckman's model

non-mediated long-term impacts on adult life outcomes (ALMOND; CURRIE; DUQUE, 2018; ALMOND; CURRIE, 2011a,b; CONTI; MASON; POUPAKIS, 2019). As mentioned in the previous section, if conditions endured in utero and neonatal health are relevant for human health through the life course, and therefore affect the life prospects that a person has, it is relevant to analyze them. A large body of empirical evidence supports that claim.

1.3.2 Empirical evidence

The idea that conditions endured early in life, including the gestational period, are a key determinant of adult health gained traction in the last quarter of the last century, when new epidemiological studies showing the association between early conditions and chronic diseases appeared. Especially relevant were David Barker's (BARKER; OSMOND; WINTER, et al., 1989; BARKER; OSMOND; LAW, 1989) studies on the association between intrauterine and early-life environment and cardiovascular disease later in life. Barker's work gave rise to the "Fetal Origins Hypothesis", according to which disruptions to the prenatal environment might cause chronic health conditions in adulthood (ALMOND; CURRIE, 2011b; CONTI; MASON; POUPAKIS, 2019).

The "Fetal Origins Hypothesis" findings were later included in the more comprehensive framework of the "Developmental Origins of Health and Disease" paradigm (CONTI; MASON; POUPAKIS, 2019). That paradigm extends the empirical findings and tries to identify the physiological mechanisms through which in utero and early-life conditions can affect adult health and disease (GLUCKMAN; HANSON, 2004; GLUCKMAN; HANSON, et al., 2008). These contributions are explicitly recognized by Heckman as a reason to include the prenatal period in his model of capabilities formation (HECKMAN, 2007; CONTI; HECKMAN, 2013, 2014).

Additionally, empirical findings showing that the prenatal environment and adverse birth outcomes are related not only with worsened health, but also educational and labor market results later in life, have raised interest among economists. Many comprehensive literature reviews summarize the main findings of studies that analyze the effect of shocks endured in utero on birth outcomes and health, education and/or labor market achievements later in life (AIZER; CURRIE, 2014; ALMOND; CURRIE, 2011a,b; ALMOND; CURRIE; DUQUE, 2018; CONTI; MASON; POUPAKIS, 2019).

The short-term impacts of in utero conditions are relevant because adverse birth outcomes are associated with worsened neonatal health. Newborns born with low birthweight (LBW), defined as birthweight under 2500 grams, have a higher risk of morbidity and mortality during the neonatal period (i.e., the first 28 days of life). Worldwide, more than 80% of neonatal deaths are in LBW newborns, of which two thirds are born preterm (PTB, i.e., less than 37 completed weeks of gestation) and one third are small-for-gestational-age (SGA, i.e., under the 10^{th} centile of weight for gestational age and sex, which indicates

intrauterine growth restriction) (BLENCOWE et al., 2019). In low-income and middle-income countries, the risk of neonatal mortality for premature newborns is more than 6 times higher than among term newborns and 1.83 times higher among newborns SGA than among newborns non-SGA (KATZ et al., 2013). Premature newborns are also more vulnerable to different conditions: respiratory distress syndrome, chronic lung disease, cardiovascular disorders, a compromised immune system, hearing and vision problems and neurological insult (BEHRMAN; BUTLER, 2007).

Adverse birth outcomes are, in turn, related with worse long-term health, education and/or labor market achievements later in life. There is evidence of PTB being associated with insulin resistance and glucose intolerance in adulthood, as well as higher risk of mental impairments and of being disabled (GLUCKMAN; HANSON, et al., 2008; MOSTER; LIE; MARKESTAD, 2008). Preterm infants are also more likely to have lower academic achievement scores and experience difficulties at school (BEHRMAN; BUTLER, 2007). Additionally, there is evidence on a negative relation between birthweight and cognitive skills in school-years, academic achievements in high school and wages in early adulthood (BHARADWAJ; EBERHARD; NEILSON, 2018; BLACK; DEVEREUX; SALVANES, 2007; FIGLIO et al., 2014; OREOPOULOS et al., 2008).

Different kinds of shocks endured in utero with impact on birth outcomes have been studied in the literature. Long-term impact of those shocks on results later in life have also been widely considered. We do not intend to reproduce in detail the results found in the literature, neither to dive into the methodological contributions (i.e., twin and siblings fixed-effects models and natural experiments) made by economists. Additionally, we do not emphasize the physiological mechanisms through which different shocks can affect health. Our goal is only to illustrate the different kinds of in utero shocks that have attracted the interest of researchers and have been proven to affect birth outcomes and/or results later in life.

A first kind of shocks are diseases, like influenza. In utero exposure to seasonal influenza has been linked to shorter gestational length (CURRIE; SCHWANDT, 2013). Additionally, in utero exposure to the influenza pandemic of 1918 has been linked to worsened educational achievements, lower wages and higher probabilities of being poor in adulthood in diverse settings, like the United States (ALMOND, 2006) and Brazil (NELSON, 2010).

There is also evidence on the relevance of nutritional shocks. One strand of evidence comes from studies on the impact of iodine supplementation. Iodine is necessary for the production of maternal and fetal thyroid hormones that regulate the development of the fetal brain and nervous system. A common public health strategy is the promotion of iodized salt. Adhvaryu et al. (2019) found that cohorts exposed in utero to the introduction of iodized salt in the United States had higher income, higher participation rates in

the labor market and higher rates of full-time work in adulthood. Field, Robles, and Torero (2009) found that an iodine supplementation program in Tanzania, previous to the introduction of iodized salt, increased the school-years attained by affected children.

An additional strand of evidence on nutritional shocks focuses on nutritional restriction. There is evidence of mild restriction, coming from ritual fasting, being associated with lower birthweight (ALMOND; MAZUMDER, 2011) and of severe restriction, due to famines, being associated with a lower probability of employment at ages around 55 (SCHOLTE; BERG; LINDEBOOM, 2015).

Economic downturns have also been studied as shocks that affect birth outcomes. A study on the impact of in utero exposure to the 2008 financial crisis in Iceland found that it led to a reduction in birthweight and an increased probability of LBW (OLAFSSON, 2016). A study on the effects of economic cyclical fluctuations in Argentina between the years 2000 and 2005 found similar results (BOZZOLI; QUINTANA-DOMEQUE, 2014). Other studies analyzed the effects of changes in the state-level unemployment rate in the United States on birthweight, LBW and PTB, with somewhat conflicting results (DEHEJIA; LLERAS-MUNEY, 2004; MARGERISON-ZILKO; LI; LUO, 2017; NOELKE et al., 2019).

There are different channels through which economic downturns can affect birth outcomes. They can lead to reduced income and, through it, affect maternal nutrition. Alternatively, downturns can lead to heightened maternal stress levels, caused by personal job loss, job loss by someone closely related or by the fear of job loss in the near future. Maternal stress is a known determinant of adverse birth outcomes (BEIJERS; BUITELAAR; WEERTH, 2014; DUNKEL SCHETTER, 2011). Finally, birth outcomes might be related to selection effects. Either selection-into motherhood, caused by the differential impact of economic downturns on fertility decisions among societal groups, or in utero selection, caused by miscarriages.

Exposure to natural disasters has also been studied as a shock that affects birth outcomes through heightened maternal stress. There is evidence linking in utero exposure to earthquakes (KIM; CARRUTHERS; HARRIS, 2017; TORCHE; SHWED, 2015) and hurricanes (CURRIE; ROSSIN-SLATER, 2013). Additionally, maternal exposure to armed violence has been studied as a maternal-stress inducing shock (QUINTANA-DOMEQUE; RÓDENAS-SERRANO, 2017; BROWN, 2018). For example, Foureaux Koppensteiner and Manacorda (2016) found that in utero exposure to local violence in Brazil, measured by the rate of homicides in public spaces, is associated to increases in the probabilities of being born PTB or LBW.

Other environmental factors that have been linked to birth outcomes, although through different causal channels, are pollution and weather fluctuations. Currie and Walker (2011) found that reduction of air pollution through less traffic congestion leads to large decreases in the incidence of prematurity and LBW in affected areas. Currie,

Graff Zivin, et al. (2013) found that drinking water pollution in the mother's residence was associated with a higher probability of being born with LBW. Rocha and Soares (2015) analyzed the impact of rainfall variations in the semiarid of the Brazilian northwest and found that increases in rainfalls are related with lower infant mortality and a higher proportion of full-term pregnancies. As the effect measured by them diminished in the areas with higher coverage of piped water and sewage system, they ascribed the relationship to drinking water scarcity and higher incidence of infectious diseases.

Different kind of policies have been analyzed as shocks that can affect birth outcomes. Policies that restrict the consumption of prejudicial substances, like alcohol (BARRECA; PAGE, 2015) or tobacco (BHARADWAJ; JOHNSEN; LØKEN, 2014), have been found to be beneficial for birth outcomes. Policies that increase the resources of families, through in-kind or cash transfers, have also been associated with better birth outcomes and neonatal health (ALMOND; HOYNES; SCHANZENBACH, 2011; GERTLER, 2004). Finally, policies that broaden access to medical care services have also been analyzed as a relevant shock associated with better birth outcomes (CURRIE; GRUBER, 1996).

Altogether, the evidence shows that the gestational period is relevant for human health at birth and through the life course and, therefore, affects the life prospects that a person has. The impact of different kinds of shocks endured in utero (i.e., disease, nutritional shocks, economic downturns, violence, pollution, natural disasters and public policies) shows that in utero environmental conditions are relevant for understanding health early in life and might have long ranging consequences. For that reason, it is important to analyze the impacts that any particular shock might have, in order to consider the relevance of protective or compensating measures.

1.4 Conclusion

The main goal of this essay was to answer if, and why, we should care about in utero environment and birth outcomes. To deal with that question, we reviewed the literature on social justice applied to health and theoretical models and empirical evidence that link in utero conditions to birth outcomes and results later in life. To conclude, we briefly summarize the link between the empirical evidence and the normative theories.

Both biomedical theories and models of human capability formation give relevance to the prenatal period as a determinant of health at birth and later in life. There is also abundant evidence that links different shocks endured in utero to adverse birth outcomes. Low birthweight and prematurity are the main indicators of health deterioration in the neonatal period and are associated with higher risk of neonatal mortality. In turn, there is evidence linking adverse birth outcomes with worse health, less educational achievements and a worse situation in the labor market (lower wages, less participation) later in life.

How does that evidence relate to the normative theories reviewed? Both Daniels' application of the *Rawlsian* theory to the relationship between health and justice and contributions made from the capabilities approach agree that societal action is needed to affect the distribution of the determinants of health, insofar as they affect the effective opportunities that individuals have to make choices coherent with the life plans they subjectively value (DANIELS, 2008; SEN, 2002; VENKATAPURAM, 2011). In that sense, health is considered of special moral importance because it contributes to the opportunities that individuals have during their lifetime. If shocks endured in utero affect birth outcomes and, therefore, have an impact in the chances of surviving the neonatal period, it seems obvious, from a normative standpoint worried with access to opportunities, that they are relevant. That argument is somewhat redundant, as any approach that values human life would argue that it is necessary to give importance to any factor that affects the chances of surviving, even more so when they are children.

Venkatapuram's (2011) notion of a capability for health allows us to grasp that relationship in a more refined way. In his view, the capability for health of a person, as well as the central human capabilities, should be understood as a dynamic and iterative system made up of different causal components, including the physical and social environments. A person's talents and skills are the result of a life-long dynamic process that, evidence and theory suggest, begins in the womb. In that sense, in utero conditions are also relevant because they are an element of the process of formation of the capabilities that a person will develop during her or his lifetime to follow ways of life that she or he subjectively values.

In this regard, it is important to consider the effects of any shocks that could affect the opportunities of individuals during their life course to make choices they ascribe value to. Any shocks endured during the gestational period that can affect birth outcomes and the long-term perspectives of health, education and income of individuals should be a concern, as they might be the source of unfair inequalities. Therefore, it is necessary to understand all effects that any particular shock might have, and consider the relevance of protective or compensating measures.

SECOND ESSAY

2 IN UTERO EXPOSURE TO ECONOMIC FLUCTUATIONS AND BIRTH OUTCOMES: AN ANALYSIS OF THE RELEVANCE OF THE LOCAL UNEMPLOYMENT RATE IN BRAZILIAN STATE CAPITALS

2.1 Introduction

Determinants of health at birth have been an important concern in biomedical sciences and epidemiology for a long time (KRAMER, 1987). More recently, social scientists, predominantly economists, have also focused on assessing the consequences of prenatal environment (ALMOND; CURRIE, 2011b; ALMOND; CURRIE; DUQUE, 2018). It has been shown that not only does prenatal environment affect birth outcomes, but it is also related with health condition and educational achievements later in life (ALMOND; CURRIE; DUQUE, 2018; CONTI; MASON; POUPAKIS, 2019).

Different kinds of socioeconomic and environmental aggregate-level shocks during gestation have been proven to have a significant effect on birth outcomes, e.g. armed violence (BROWN, 2018; QUINTANA-DOMEQUE; RÓDENAS-SERRANO, 2017), air pollution (CURRIE, 2013), and natural disasters (TORCHE, 2011; KIM; CARRUTHERS; HARRIS, 2017). Among them, economic downturns have attracted attention from many studies. Most studies have shown a positive relationship between maternal exposure to acute economic downturns (OLAFSSON, 2016; BOZZOLI; QUINTANA-DOMEQUE, 2014; MARGERISON-ZILKO; LI; LUO, 2017) or regular economic cycle contractions (BOZZOLI; QUINTANA-DOMEQUE, 2014; MARGERISON-ZILKO; LI; LUO, 2017; WEHBY; GIMENEZ; LÓPEZ-CAMELO, 2017; NOELKE et al., 2019) during pregnancy and adverse birth outcomes. However, some studies have shown a negative association (DEHEJIA; LLERAS-MUNEY, 2004), presumably due to selection effects. Some of those studies have used negative variations in the unemployment rate at subnational levels as an indicator of economic slowdowns (MARGERISON-ZILKO; LI; LUO, 2017; NOELKE et al., 2019; WEHBY; GIMENEZ; LÓPEZ-CAMELO, 2017).

Most frequently studied birth outcomes are birthweight, gestational age and intrauterine growth restriction. Low birthweight (LBW, < 2500 grams), preterm birth (PTB, < 37 weeks of gestation), and the newborn being small-for-gestational-age (SGA, birthweight beneath the 10^{th} percentile of the weight for gestational age distribution) are the main causes of neonatal death among children born without congenital anomalies (BHUTTA et al., 2005). Those conditions are also associated with adverse health, as well

as worse educational and labor market results, later in life (BARKER, 2006; FIGLIO et al., 2014; BLACK; DEVEREUX; SALVANES, 2007; MOSTER; LIE; MARKESTAD, 2008).

It is possible to think about three different mechanisms through which prenatal economic environment might affect birth outcomes: selection effects, maternal stress, and maternal nutrition. One kind of selection effect is the selection-into-motherhood caused by the differential impact of economic downturns on fertility decisions among societal groups. Economic downturns might affect fertility decisions of prospective mothers with different observable or unobservable characteristics. If, for example, economic downturns lead to a relative decrease in pregnancy rates among women with higher risk of having early term pregnancies or underweight babies, we would observe a negative association between economic slowdowns and adverse birth outcomes. A seminal study that analyzed births in the United States between 1975 and 1999 showed that unemployment rates in the year before conception were associated with decreased rates of low birthweight and reduced neonatal mortality and attributed this association to reduced fertility among black women with low education, i.e. the most vulnerable group in that country (DEHEJIA; LLERAS-MUNEY, 2004).

An additional kind of selection effect is in utero selection. Some studies have shown that heightened maternal stress caused by exposure to economic downturns is associated with pregnancy loss, mainly among male fetuses exposed during mid-pregnancy (BRUCKNER; MORTENSEN; CATALANO, 2016; CATALANO et al., 2005). Even though the biological reasons are unclear, the empirical evidence of this in utero selection effect is ample and has also been found associated with in utero exposure to stressors other than economic downturns (BRUCKNER; CATALANO, 2018).

Exposure to economic downturns can lead to heightened maternal stress levels, caused by personal job loss, job loss by someone closely related or by the fear of job loss in the near future (MARGERISON-ZILKO, 2010). Prenatal maternal stress is thought to be related with health at birth through the hypothalamic–pituitary–adrenal axis (HPA axis). When a pregnant woman is exposed to stress, the HPA axis is activated and heightens the levels of cortisol, which in turn leads to higher levels of placental corticotrophin-releasing hormone (CRH). Increased levels of CRH are associated with decreased fetal growth and preterm delivery (WADHWA et al., 2004; BEIJERS; BUITELAAR; WEERTH, 2014). Even though this mechanism is widely accepted as relevant, it is possible that heightened maternal stress during pregnancy affects birth outcomes also through other mechanisms, like a depressed immune system, which increases the risk of inflammatory reactions that might lead to preterm birth (DUNKEL SCHETTER, 2011). Also, higher stress levels might lead to prejudicial habits or health behaviors, like smoking or drinking alcohol, which could also be prejudicial for the newborn (BEIJERS; BUITELAAR; WEERTH, 2014).

Additionally, economic downturns might lead to job losses or income reduction, which can diminish the consumption of health enhancing products, mainly a nutritionally healthy diet (MARGERISON-ZILKO, 2010). The gestational period has specific requirements in terms of caloric intake, as well as intake of essential nutrients like proteins, fatty acids and folate; and a wide array of studies have shown positive association between appropriate nutrition and a reduction in adverse birth outcomes (ABU-SAAD; FRASER, 2010).

In population-based observational studies, it is usually not possible to disentangle the specific mechanism through which in utero exposure to an adverse economic environment affects birth outcomes. Administrative data on birth records usually do not include any direct measure of either maternal stress or nutrition during pregnancy. In face of those data constraints, different studies have used the timing of exposure as an indirect way of identifying the causal mechanism. Adverse birth outcomes linked to maternal exposure to economic downturns at the beginning of the gestation -i.e., the first trimester- are considered an indicator of the stress-induced pathway (OLAFSSON, 2016; BOZZOLI; QUINTANA-DOMEQUE, 2014; MARGERISON-ZILKO; LI; LUO, 2017). Adverse birth outcomes linked to exposure during the last trimester of gestation are interpreted as an indicator of nutritional constraints affecting birth outcomes (BOZZOLI; QUINTANA-DOMEQUE, 2014; STEIN; LUMEY, 2000). However, there are contending arguments to the validity of that strategy, as evidence on the specific time window in which stress or nutritional shocks during pregnancy affect birth outcomes is not conclusive (BEIJERS; BUITELAAR; WEERTH, 2014; DUNKEL SCHETTER, 2011; ABU-SAAD; FRASER, 2010).

Some specific studies about the impact of in utero exposure to economic slowdowns deserve comment. A study on the impact of in utero exposure to the 2008 financial crisis in Iceland found that it led to a reduction in birthweight, an increased probability of LBW and a reduction in the proportion of boys born -consistent with the in-utero selection mechanism- when it happened during the first trimester of gestation. The author suggests the maternal stress mechanism as possible explanation (OLAFSSON, 2016).

A study on economic cyclical fluctuations in Argentina between the years 2000 and 2005 found that average birthweight decreases and the probabilities of being born with LBW increases when the economic activity slows down in the period 9 to 7 months before birth, which the authors judge as consistent with the stress hypothesis (BOZZOLI; QUINTANA-DOMEQUE, 2014). The same study found that exposure of less educated mothers, who are presumably more financially vulnerable, to economic downturns in the three months before birth is also associated with lower birthweight and higher probabilities of being born with LBW. The authors interpret that second finding as an indication of the nutritional mechanism.

An additional study used changes in the state-level unemployment rate in the United States 1990 and 2013 as an indicator of economic slowdowns. The authors found that an increase in the unemployment rate during the first trimester of pregnancy was associated with increased odds of PTB, and that relationship was larger during the 2007–2009 financial crisis (MARGERISON-ZILKO; LI; LUO, 2017). Increases in the unemployment rate during the second trimester of gestation were found to be associated with decreased odds of PTB. According to the authors, unreported results pointed in the same direction considering LBW as the outcome variable.

A similar study analyzed the association between variations in state level unemployment and birth outcomes in the United States between 1976 and 2016. The authors found that a one percentage point increase in the state unemployment rate during the first gestational trimester increases 0.1 percentage points the probability of preterm birth, but a one percentage point increase in the state unemployment rate during the second and third trimester reduces the probability of prematurity by 0.06 percentage points (NOELKE et al., 2019). They interpret the results as being possibly driven by two contrasting effects of economic downturns on maternal health: while recessions increase maternal exposure to socioeconomic stressors like income or job loss, they also diminish mothers' exposure to work related and environmental stressors. According to them, it is probable that hazardous effects dominate protective effects during the first gestational trimester, but not in later stages of pregnancy. It is also worth noting that the authors found heterogeneity in the results among different groups: among less educated black women the association was around three times larger in magnitude than among more educated white women.

The goal of our study was to analyze the association between economic environment during the pregnancy and birth outcomes in Brazil. We seek to contribute both to the literature on the impact of in utero exposure to economic downturns on birth outcomes (OLAFSSON, 2016; BOZZOLI; QUINTANA-DOMEQUE, 2014; MARGERISON-ZILKO; LI; LUO, 2017; WEHBY; GIMENEZ; LÓPEZ-CAMELO, 2017) and to the literature on the effects of environmental factors during pregnancy on health at birth in the Brazilian context (ROCHA; SOARES, 2015; RASELLA; AQUINO; BARRETO, 2010; SILVEIRA et al., 2019). We used quarterly data on urban unemployment rates in the 27 Brazilian state capitals and linked it to birth records from the Brazilian vital statistics system, according to the mother's municipality of residence, to estimate the association between the local unemployment rate during pregnancy and birth outcomes. Additionally, we measured the unemployment rate at different times of the pregnancy to evaluate if the timing of exposure to variations in local unemployment rates mattered and if there were problems of selection into motherhood or in utero selection.

We found that a 1 percentage point increase in the local unemployment rate in the trimester before birth is associated with 2.68% higher odds of being born with very low

birthweight (VLBW, < 1500 grams) (OR: 1.0268, 95%CI: 1.0006–1.0536). That result is pushed by the effect among newborns from mothers younger than 24 (6.84% higher odds of being born with VLBW, OR: 1.0684, 95%CI: 1.0353–1.1024), from mothers with 11 years of schooling or less (4.77% higher odds of being born with VLBW, OR: 1.0477, 95% CI: 1.0245–1.0714), and from brown or black mothers (3.87% higher odds of being born with VLBW, OR: 1.0387, 95%CI: 1.0156–1.0624). The association among children born from younger, less educated and black or brown mothers are robust to the application of a procedure controlling for multiple testing, albeit the results considering the whole sample are not. These results suggest that children born from women of low socioeconomic status are more vulnerable to in utero exposure to economic downturns.

2.2 Methods

2.2.1 Data

In order to assess the birth outcomes, we used microdata from the SINASC-DATASUS, the System of Information on Live Births from the Department of Informatics of the *Sistema Unico de Saúde*, i.e., the Brazilian National Health Service. Data are open access and available online[1]. Data are duly anonymized before being released. Each observation corresponds to one live birth and provides information on the pregnancy, newborn, and maternal characteristics. Registration of birth information on the system is mandatory for all births in the Brazilian territory.

We first selected data from all births between 2012 and 2016 from mothers residing in the 27 state capitals (n = 3,564,044), because those are the years for which both unemployment rates at the subnational level and data from live births are available. We kept data only from singleton births (n = 3,478,142), because birth outcomes in multiple births, specially birthweight, are significantly different. We then merged the data with the estimated unemployment rates in the mother's city of residence. Information of unemployment at the municipality level is only available with quarterly frequency for the capitals of the 27 states, which are the units of the Federative Republic of Brazil. As data on local levels of unemployment are available from January 2012, we had to drop all births previous to October 2012 to have the local unemployment rate in the 9 months before the month of birth. Our final sample consisted on data of 2,952,430 live singleton births from mothers residing in any of the 27 Brazilian state capitals, born between October 2012 and December 2016.

[1] `http://datasus.saude.gov.br/transferencia-de-arquivos` (last accessed: 20/02/2020)

2.2.1.1 Dependent variables

We used data on the following outcome variables: birthweight, gestational age, and sex. We considered sex as an outcome variable because there is evidence of a link between stress inducing events and a decline in the proportion of male births (BRUCKNER; MORTENSEN; CATALANO, 2016; CATALANO et al., 2005). We kept birthweight (in grams) and gestational age (in weeks) as numerical variables. All cases in which one of these variables was coded as "Ignored" were re-coded as a missing value, and therefore dropped from regressions. The "sex" variable was re-coded as a binary variable indicating if the newborn was female or not ("female"). We created also binary variables for low birthweight (LBW, <2500 grams), very low birthweight (VLBW, <1500 grams), preterm birth (PTB, < 37 weeks of gestation), very preterm birth (VPTB, < 32 weeks), and small for gestational age (SGA, birthweight beneath the 10^{th} percentile of weight for gestational age, according to the "International Newborn Size Standards" of the INTERGROWTH-21^{st} Project (VILLAR et al., 2014))

2.2.1.2 Explanatory variable

Our explanatory variable is the mean local unemployment rate in the city where the mother resided during the pregnancy. We constructed that variable as the mean unemployment rate in the 9 months before the month of birth in the city (state capital) where the mother resided. We used the quarterly unemployment rate estimated by the Brazilian Institute of Geography and Statistics (IBGE), using the Continuous National Household Sample Survey (*PNAD Contínua*), for the 27 state capitals. Data are available on the website of the IBGE[2].

As the original data are not available with a monthly frequency, we constructed a mean unemployment rate in the 9 months before the month of birth as a weighted mean of quarterly local unemployment rates. For newborns born in January, April, July, and October, the mean unemployment rate coincided with the mean of the previous three quarterly unemployment rates. For newborns conceived in other months, we estimated a weighted mean of the unemployment rate in the quarter of conception and the three previous ones. For example, the mean unemployment rate for a newborn conceived in February 2014 was the weighted mean of the unemployment rate in the first quarter of 2014 (with weight of 2/3, to account for February and March), the second and third quarter of 2014 (both with weight of 1, to account for the months from April to September), and the fourth quarter of 2014 (with weight of 1/3, to account for October). We did the same for the months 1 to 3, 4 to 6, and 7 to 9 before birth to approximate the unemployment rate in the mother's city of residence during each trimester of gestation.

[2] `https://sidra.ibge.gov.br/tabela/4099#/n6/all/v/4099/p/first%2020/d/v4099%201/l/v,p,t/resultado` (last accessed: 10/04/2019)

2.2.1.3 Covariates

We included as covariates several maternal characteristics, namely: race (white, black, Asian, brown, native, ignored), years of education (none, 1 to 3, 4 to 7, 8 to 11, 12 or more, ignored), marital status (single, married, widow, divorced, stable union, ignored). All missing values in these categorical variables were categorized with the preexisting category "ignored" to avoid losing those observations in our regressions. In two different robustness checks, we tried both re-coding all values originally categorized as "ignored" as missing values and keeping data exactly as original.

Some clarification about the race variable in the Brazilian context is needed. "Brown" is the literal translation of the *pardo* category, which is used to refer to individuals of multiracial background. According to official estimations for the last quarter of 2016, 43.8% of Brazilians were white, 47.2% brown, and 8.2% black. White Brazilians tend to be from higher socioeconomic status. This is reflected in inequalities in the labor market. Among the working population, in the last quarter of 2016, mean monthly income was approximately R$2,660 Brazilian *reais* for white individuals, R$1,461 for black individuals, and R$1,480 for brown individuals. Unemployment rates were also divergent: 9.5% among white people, 14.4% among black people, and 14.1% among brown people (IBGE, 2017).

We re-coded the age of the mother (originally in years) and created four different binary variables: 19 years old or less, 20 to 24 years old, 25 to 34 years old, 35 years old or more. We also re-coded the variables indicating the number of children dead or alive into two binary variables indicating if the mother had at least one other child dead or alive. In the Brazilian vital registration system, miscarriages are recorded as dead children.

We included also 12 fixed effects for the month of birth, 5 for the year of birth, and 27 for the mother's municipality of residence, as well as the full set of pairwise interactions between fixed-effects.

2.2.2 Empirical strategy

To estimate the association between the unemployment rate in the mother's city of residence during pregnancy and birth outcomes, we used a fixed-effects model of the following form:

$$y_{icma} = \alpha + \beta U_{cma} + X_i\gamma + M_m + A_a + C_c + \theta_{ca} + \nu_{ma} + \eta_{mc} + \varepsilon_{icma} \tag{2.1}$$

Where y_{icma} is one of the dependent variables described above, indicating birth outcomes for newborn i, born in the state capital c, in month m, and year a. U_{cma} is the estimated mean unemployment rate in the city c during the 9 months before the month m in the year a. The coefficient β, which measures the association between birth outcomes and unemployment rate during pregnancy, is the one of interest. X_i is a vector

of maternal characteristics (age, race, years of education, marital status, previous children alive or deceased) for newborn i. M_m is a month-of-birth fixed effect to account for seasonal patterns in neonatal health. A_a is year-of-birth fixed effect to account for possible shocks at the aggregate level. C_c is a fixed effect for each state capital city of residence of the mothers to control for underlying time-invariant differences among municipalities. θ_{ca} is an interaction term between the city of residence and the year fixed effects to account for time varying factors at the local level. ν_{ma} is an interaction term between the month and the year of birth fixed effects to account to time varying factors from month to month at the national level. η_{mc} is an interaction term between the month-of-birth and the city of residence fixed effects to account for local seasonality.

To analyze the timing of the association between variations in the unemployment rate during pregnancy and birth outcomes, we estimated also a fixed-effects model of the following form:

$$y_{icma} = \alpha + \sum_{T=1}^{3} \beta_T U_{Tcma} + X_i\gamma + M_m + A_a + C_c + \theta_{ca} + \nu_{ma} + \eta_{mc} + \varepsilon_{icma} \qquad (2.2)$$

Where $T = 1$ indicates the months 7 to 9, $T = 2$ the months 4 to 6, and $T = 3$ the months 1 to 3 before the month of birth, and serves as proxy for the first, second and third gestational trimester, respectively. In all cases, we estimated the model by Ordinary Least Squares when the outcome variable was continuous (birthweight, gestational age) and by logistic regression (*logit* model) when the outcome variable was binary (LBW, VLBW, PTB, VPTB, SGA, female). Standards errors were clustered at the municipality level to correct for autocorrelation, as is recommended when working with data from repeated cross-sections (BERTRAND; DUFLO; MULLAINATHAN, 2004; COLIN CAMERON; MILLER, 2015) and was done in many previous studies similar to ours (BROWN, 2018; OLAFSSON, 2016; BOZZOLI; QUINTANA-DOMEQUE, 2014; WEHBY; GIMENEZ; LÓPEZ-CAMELO, 2017; NOELKE et al., 2019; DEHEJIA; LLERAS-MUNEY, 2004; FOUREAUX KOPPENSTEINER; MANACORDA, 2016).

We estimated all models directly from individual observations, which is equivalent to using grouped data with cells defined by all existing combinations of values of the categorical variables, weighted by the frequency of each combination. For the cases estimated by OLS (birthweight and gestational age), the coefficients can be interpreted as the marginal effect of a 1 percentage point increase in the local unemployment rate. For the cases estimated by *logit*, we report the odds ratio, which show the change in the odds of the different birth outcomes associated with a 1 percentage point increase in the local unemployment rate.

2.3 Results

2.3.1 Descriptive analysis

Table 2.1 shows descriptive statistics for all live births from singleton pregnancies from mothers residing in Brazilian state capitals and in the rest of Brazil between October 2012 and December 2016. There are relevant differences both in birth outcomes and in maternal characteristics among the two groups. Our analysis is restricted only to births in state capitals, the only cities with available information on the local unemployment rate.

In state capitals, mean birthweight is smaller, and there is a higher proportion of newborns with LBW and VLBW. Mean gestational age is shorter and there is a higher proportion of VPTB. The proportion of PTB and newborns SGA is smaller.

Mothers in state capitals are comparatively older and more educated, and the proportion without a partner (single, widow or divorced) is higher. Among them, the proportion of black and brown mothers is higher than in the rest of the country; and the proportion of white mothers is smaller.

2.3.2 Regression analysis

Table 2.2 shows the results of estimating model 2.1 (panel A) and model 2.2 (panel B). The association between a one percentage point (p.p.) increase in the mean local unemployment rate during pregnancy in the city (state capital) of residence of the mother and birth outcomes does not reach the 5% threshold of significance for any outcome (Table 2, panel A). Considering the mean unemployment rate in the months 1 to 3, 4 to 6, and 7 to 9 before birth -which serve as a proxy for the unemployment rate at the different gestational trimesters-, a 1 p.p. increase in the local unemployment rate in the trimester before birth is associated with a 1.8 grams lower birthweight (95% Confidence Interval: -3.42 - -0.17) and with 2.68% higher odds of being born with VLBW (OR: 1.0268, 95% CI: 1.0006–1.0536).

Table 2.3 shows the results of some robustness exercises for the results found in the estimation of model 2.2. We only used birthweight related outcome variables, as they are the only ones for which we found associations with the local unemployment rate during pregnancy. We ran the same regression of columns 1, 2 and 3 of panel B of Table 2.2, but with alternative ways of managing the missing values in three maternal characteristics: level of education, race, and marital status. Either re-categorizing values “ignored” as missing values or leaving “ignored” values and missing values as in the original data did not substantially alter our original results. We also ran the regressions without considering the race of the mother, because it is the covariate with the largest proportion of missing data or classified as ignored, and it did not alter our results either. The association between

Table 2.1 – Summary statistics, live births in Brazilian state capitals and in Brazil (October 2012 – December 2016)

	State capitals	Rest of Brazil	Difference
N =	2,952,430	9,223,182	
Birth outcomes			
Birthweight			
Mean birthweight in grams (SD)	3191.8 (547.8)	3204.1 (536.4)	-12.3***
LBW (%)	7.83	7.22	0.61***
VLBW (%)	1.32	1.10	0.22***
Missing data (%)	0.00	0.03	-0.03***
Gestational age			
Mean gestational age in weeks (SD)	38.5 (2.1)	38.6 (2.2)	-0.1***
PTB (%)	10.15	10.62	-0.47***
VPTB (%)	1.44	1.39	0.05***
Missing data (%)	2.46	3.66	-1.2***
Other birth outcomes			
SGA (%)	7.04	7.47	-0.43***
Missing data (%)	2.46	3.70	-1.24***
Female (%)	48.74	48.75	-0.01
Missing data (%)	0.02	0.27	-0.25***
Maternal characteristics			
Age (%)			
≤ 19	15.49	19.70	-4.21***
20 - 24	23.02	26.04	-3.02***
25 - 34	46.13	42.88	3.25***
≥ 35	15.35	11.37	3.98***
Missing data	0.00	0.20	-0.2***
Education (%)			
None	0.20	0.75	-0.55***
1 to 3 years	1.58	3.61	-2.03***
4 to 7 years	14.71	21.14	-6.43***
8 to 11 years	56.74	57.91	-1.17***
12 years and more	25.72	14.73	10.99***
Ignored (includes missing data)	1.05	1.86	-0.81***
Race (%)			
Brown	54.85	53.09	1.76***
White	32.46	36.37	-3.91***
Black	6.15	4.83	1.32***
Asian	0.60	0.30	0.3***
Native	0.25	0.93	-0.68***
Ignored (includes missing data)	5.69	4.48	1.21***
Marital Status (%)			
Married	32.88	32.31	0.57***
Single	46.36	39.39	6.97***
Widow	0.14	0.19	-0.05***
Consensual Union	18.75	25.79	-7.04***
Divorced	1.07	1.05	0.02***
Ignored (includes missing data)	0.79	1.27	-0.48***
Previous children (%)			
At least 1 child alive	55.34	57.60	-2.26***
Missing data	7.41	5.54	1.87***
At least 1 child not alive	20.70	17.90	2.80***
Missing data	11.33	8.36	2.97***

Note: all data are from SINASC-DATASUS. LBW: low birthweight (< 2500 grams). VLBW: very low birthweight (< 1500 grams). PTB: preterm birth (< 37 weeks). VPTB: very preterm birth (< 32 weeks). SGA: small for gestational age (birthweight beneath the $10th$ percentile of weight for gestational age). Significance of the differences was estimated by a two-sample t-test for means (birthweight and gestational age) or a two-sample test of proportions (all other variables). * p-value < 0.1; ** p-value < 0.05; *** p-value < 0.01.

Table 2.2 – Unemployment rate at the mother city of residence and birth outcomes

	(1) Birthweight	(2) LBW	(3) VLBW	(4) Gestational Age	(5) PTB	(6) VPTB	(7) SGA	(8) Female
PANEL A								
UR months 1 to 9 before birth	-1.6593	1.0080	1.0100	-0.0120*	0.9973	1.0263	0.9914	0.9961
95% CI	(-4.3402 - 1.0216)	(0.9937 - 1.0225)	(0.9770 - 1.0440)	(-0.0250 - 0.0011)	(0.9856 - 1.0091)	(0.9931 - 1.0606)	(0.9769 - 1.0061)	(0.9889 - 1.0033)
P value	0.2146	0.2749	0.5588	0.0712	0.6490	0.1223	0.2482	0.2874
Observations	2,594,223	2,594,223	2,594,223	2,552,977	2,555,192	2,555,192	2,579,539	2,593,733
PANEL B								
UR months 7 to 9 before birth	-0.6581	1.0035	1.0099	-0.0064	0.9943	1.0100	0.9992	0.9995
95% CI	(-2.4943 - 1.1781)	(0.9960 - 1.0110)	(0.9846 - 1.0358)	(-0.0148 - 0.0020)	(0.9831 - 1.0056)	(0.9940 - 1.0261)	(0.9885 - 1.0101)	(0.9949 - 1.0040)
P value	0.4679	0.3597	0.4468	0.1302	0.3215	0.2220	0.8915	0.8196
UR months 4 to 6 before birth	0.3802	1.0010	0.9817	-0.0024	1.0057	0.9962	0.9900	0.9987
95% CI	(-1.3624 - 2.1228)	(0.9910 - 1.0111)	(0.9577 - 1.0064)	(-0.0103 - 0.0055)	(0.9963 - 1.0151)	(0.9736 - 1.0192)	(0.9736 - 1.0067)	(0.9920 - 1.0054)
P value	0.6575	0.8489	0.1445	0.5424	0.2337	0.7416	0.2393	0.7059
UR months 1 to 3 before birth	-1.7953**	1.0040	1.0268**	-0.0029	0.9962	1.0265*	1.0045	0.9975
95% CI	(-3.4172 - -0.1735)	(0.9905 - 1.0177)	(1.0006 - 1.0536)	(-0.0128 - 0.0070)	(0.9851 - 1.0075)	(0.9988 - 1.0549)	(0.9922 - 1.0171)	(0.9916 - 1.0035)
P value	0.0314	0.5650	0.0447	0.5553	0.5126	0.0613	0.4725	0.4169
Observations	2,594,223	2,594,223	2,594,223	2,552,977	2,555,192	2,555,192	2,579,539	2,593,733

Note: The table shows the association between the mean local unemployment rate in the 9 months (Panel A) and in the months 1 to 3, 4 to 6 and 7 to 9 (Panel B) before birth in the city where the mother resided and different birth outcomes. Standard errors are clustered at the city level. UR: unemployment rate. LBW: low birthweight. VLBW: very low birthweight. PTB: preterm birth. VPTB: very preterm birth. SGA: small for gestational age. All regressions included as covariates binary variables indicating: age of the mother (younger than 19 years old, between 20 and 24, between 25 and 34, older than 35), marital status of the mother (single, married, widow, divorced, consensual union, ignored), race/ethnicity of the mother (Asian, white, native, brown, black), years of education of the mother (None, 1 to 3, 4 to 7, 8 to 11, 12 or more), the mother had a previous child alive, the mother had a previous child dead. All regressions included fixed effects for: mother city of residence, month of birth, year of birth. All regressions included two-way interactions between the fixed effects. * p value < 0.1; ** p value < 0.05; *** p value < 0.01.

the mean unemployment rate in the mother city of residence during the three months before birth and the odds of being born with VLBW remained robust and, therefore, we further focused exclusively on this outcome.

Table 2.4 shows the results of estimating model 2.2 for different groups of mothers, to see if there are heterogeneities in the association between in utero exposure to variations in the local unemployment rate and VLBW, i.e. the birth outcome for which we found an association with the local unemployment rate during pregnancy. No relevant differences were found when we segmented the sample between children from mothers with a partner (married or in a consensual union) and from mothers without a partner (single, divorced or widow).

Among newborns from mothers younger than 24, a 1 p.p. increase in the mean unemployment rate in the mother's city of residence during the months 9 to 7 before birth is associated with 5.23% higher odds of being born with VLBW (OR: 1.0523, 95%CI: 1.0115–1.0948). The mean unemployment rate in the last trimester before birth is associated with 6.84% higher odds of being born with VLBW (OR: 1.0684, 95%CI: 1.0353–1.1024). No significant association was found among newborns from mothers 25 or older.

Considering level of education, among newborns from mothers with 11 years of schooling or less a 1 p.p. increase in the local unemployment rate during the months 1 to 3 before the month of birth was associated with 4.77% higher odds of being born with VLBW (OR: 1.0477, 95% CI: 1.0245–1.0714). No significant association was found among newborns from mothers with 12 or more years of education.

We also analyzed the association between in utero exposure to fluctuations in the local unemployment rate and the odds of being born with VLBW separately for children born from white and for black or brown mothers. The rationale for that separation is that, during our period of analysis, mean income from work and unemployment rates among the black and brown population were similar and notably worse than among the white population (IBGE, 2017). Children from Asian and native mothers were not considered because they were a very small proportion of our data. Among children from brown of black mothers, a 1 p.p. increase in the unemployment rate during the last trimester before birth was associated with 3.87% higher odds of being born with VLBW (OR: 1.0387, 95%CI: 1.0156–1.0624). No significant association was found among newborns from white mothers, although it is worth noting that the sign of the association is the opposite.

Unemployment rates could differentially affect the fertility decisions made by women and, therefore, introduce a selection bias. If that were the case, the odds of the mother having a certain characteristic would change in response to changes in the local unemployment rate. We regressed different maternal characteristics on the local unemployment rate in the months 10 to 18 (Table 2.5 - Panel A) and in the months 10 to 12 (Table 2.5 - Panel B) before birth to check if that was the case in our data. As quarterly

Table 2.3 – Unemployment rate at the mother city of residence and birth outcomes, robustness checks

	Ignored as missing			Same as original			Without controlling for race		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Birthweight	LBW	VLBW	Birthweight	LBW	VLBW	Birthweight	LBW	VLBW
UR months 7 to 9 before birth	-0.5242	1.0015	1.0108	-0.5014	1.0019	1.0083	-0.6140	1.0034	1.0100
95% CI	(-2.4335 - 1.3851)	(0.9943 - 1.0088)	(0.9858 - 1.0365)	(-2.4040 - 1.4012)	(0.9948 - 1.0091)	(0.9835 - 1.0338)	(-2.4610 - 1.2331)	(0.9959 - 1.0110)	(0.9846 - 1.0360)
P value	0.5774	0.6827	0.4004	0.5927	0.5987	0.5140	0.5005	0.3714	0.4437
UR months 4 to 6 before birth	0.5697	0.9992	0.9822	0.4524	0.9994	0.9840	0.3750	1.0010	0.9818
95% CI	(-1.0923 - 2.2317)	(0.9895 - 1.0090)	(0.9566 - 1.0085)	(-1.2511 - 2.1559)	(0.9897 - 1.0092)	(0.9586 - 1.0100)	(-1.3577 - 2.1077)	(0.9911 - 1.0109)	(0.9578 - 1.0064)
P value	0.4873	0.8746	0.1821	0.5898	0.9084	0.2258	0.6601	0.8443	0.1451
UR months 1 to 3 before birth	-1.6919*	1.0055	1.0268**	-1.7921**	1.0061	1.0278**	-1.7360**	1.0038	1.0263**
95% CI	(-3.4614 - 0.0776)	(0.9930 - 1.0182)	(1.0016 - 1.0528)	(-3.5706 - -0.0137)	(0.9936 - 1.0188)	(1.0030 - 1.0532)	(-3.3702 - -0.1018)	(0.9903 - 1.0175)	(1.0001 - 1.0532)
P value	0.0601	0.3909	0.0372	0.0484	0.3420	0.0278	0.0382	0.5806	0.0493
Observations	2,457,972	2,457,972	2,457,972	2,474,646	2,474,646	2,474,646	2,594,223	2,594,223	2,594,223

Note: The table shows the association between the mean local unemployment rate in the months 1 to 3, 4 to 6 and 7 to 9 before birth in the city where the mother resided and birth outcomes. Standard errors are clustered at the city level. UR: unemployment rate. LBW: low birthweight. VLBW: very low birthweight. All regressions included as covariates binary variables indicating: the age, marital status, education, and previous children alive or not of the mother; as well as fixed effects for mother city of residence, month of birth and year of birth, and two-way interactions between the fixed effects. Columns 1 to 6 also included the race of the mother as a covariate. In columns 1 to 3, all observations with race, marital status or education classified as ignored were re-coded as missing values. In columns 4 to 6, all "ignored" and missing values in those three variables were kept as in the original data. * p value < 0.1; ** p value < 0.05; *** p value < 0.01.

Table 2.4 – Unemployment rate at the mother city of residence and VLBW

	Age		Marital status		Race/ethnicity		Years of education	
	≤ 24 years	≥ 25 years	Partner	No Partner	Black or Brown	White	11 or less	12 or more
Dependent variable: VLBW	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
UR months 7 to 9 before birth	1.0523**	0.9815	1.0195	1.0019	1.0111	0.9858	1.0224	0.9788
95% CI	(1.0115 - 1.0948)	(0.9526 - 1.0114)	(0.9941 - 1.0456)	(0.9676 - 1.0373)	(0.9858 - 1.0371)	(0.9326 - 1.0421)	(0.9918 - 1.0539)	(0.9389 - 1.0203)
P value	0.0116	0.2228	0.1338	0.9169	0.3938	0.6145	0.1528	0.3120
UR months 4 to 6 before birth	0.9636	0.9929	0.9843	0.9789	0.9880	0.9754	0.9740*	1.0104
95% CI	(0.9136 - 1.0164)	(0.9617 - 1.0252)	(0.9436 - 1.0268)	(0.9451 - 1.0139)	(0.9604 - 1.0164)	(0.9153 - 1.0395)	(0.9440 - 1.0049)	(0.9360 - 1.0907)
P value	0.1732	0.6635	0.4626	0.2348	0.4036	0.4430	0.0986	0.7912
UR months 1 to 3 before birth	1.0684***	0.9992	1.0354*	1.0080	1.0387***	0.9946	1.0477***	0.9561
95% CI	(1.0353 - 1.1024)	(0.9633 - 1.0364)	(0.9938 - 1.0787)	(0.9781 - 1.0388)	(1.0156 - 1.0624)	(0.9247 - 1.0697)	(1.0245 - 1.0714)	(0.8934 - 1.0233)
P value	0.0000	0.9650	0.0965	0.6049	0.0009	0.8834	0.0000	0.1950
Observations	975,113	1,619,110	1,339,859	1,236,633	1,550,041	910,334	1,903,439	667,077

Note: The table shows the association between the mean local unemployment rate in the months 1 to 3, 4 to 6 and 7 to 9 before birth in the city where the mother resided for different groups of mothers. Standard errors are clustered at the city level. UR: unemployment rate. VLBW: very low birthweight. All regressions included covariates for previous children alive or not, fixed effects for mother city of residence, month of birth and year of birth, and two-way interactions between the fixed effects. Columns 1 and 2 included also marital status, race and education. Columns 3 and 4 included also age, race and education. Columns 5 and 6 included also age, marital status and education. Columns 7 and 8 included age, marital status, and race. * p value < 0.1; ** p value < 0.05; *** p value < 0.01.

unemployment rates at the local level were available from beginning 2012, we had to drop all births before July 2013 to have data from unemployment rates at the mother city of residence in months 10 to 18 before birth. The results, depicted in Table 5, show no significative association between the local unemployment rate dynamics before conception and the odds of the mother: being younger or older than 24 years old, having a stable partner or not, being black or brown or being white, having up to 11 years of education or 12 or more. Granted, we cannot discard the existence of a selection into motherhood phenomenon according to non-observable characteristics.

A frequently cited problem with studies that report many tests, such as ours, is that the probabilities of rejecting the null hypothesis increase with the number of regressions. To assess to which extent our results were affected by multiple testing, we applied the false discovery rate controlling procedure suggested by Benjamini and Hochberg (1995). The results can be found in Table A.1 in the appendix. Adopting a false discovery rate (i.e., the expected proportion of errors among the rejected null hypotheses) of 0.05, we found that our main results from Table 2.4 stay significant. That gives us confidence that the association found between economic downturns during the last trimester of pregnancy and higher odds of being born with VLBW among children born from less educated, black or brown and younger women is not a result of multiple testing. The association found between exposure during the last trimester and higher odds of being born with VLBW for the whole sample did not stand the false discovery rate controlling procedure.

2.4 Discussion

Our results show that increases in local unemployment rates during pregnancy are associated with lower birthweight and higher odds of being born with VLBW among newborns from mothers who resided in the 27 Brazilian state capitals. The association is detectable in the last trimester before birth among newborns from younger, less educated and black or brown mothers. Our results also show that local unemployment rates before conception are not correlated with maternal characteristics (age, marital status, race, education), which suggests that our results are not biased by a selection-into-motherhood effect.

Our results are in line with previous results from economic downturns in a developing country context that suggested a positive effect of economic downturns during the third gestational trimester on the prevalence of LBW among children born from less educated mothers (BOZZOLI; QUINTANA-DOMEQUE, 2014). In the Brazilian context, younger, less educated and brown or black mothers are more likely to be from low socioeconomic status and, therefore, their children are more likely to have worse birth outcomes (SILVEIRA

Table 2.5 – Unemployment rate before conception and selection into motherhood

	Age		Marital status		Race/ethnicity		Education	
	≤ 24 years	≥ 25 years	Partner	No Partner	Black or Brown	White	11 years or less	12 years or more
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PANEL A								
UR months 10 to 18 before birth	0.9974	1.0026	0.9923	1.0078	1.0171	0.9869	0.9994	1.0006
95% Confidence Interval	(0.9873 - 1.0077)	(0.9924 - 1.0129)	(0.9676 - 1.0175)	(0.9828 - 1.0334)	(0.9931 - 1.0418)	(0.9644 - 1.0099)	(0.9849 - 1.0141)	(0.9861 - 1.0154)
P value	0.6203	0.6203	0.5449	0.5449	0.1646	0.2627	0.9314	0.9314
Observations	2,427,273	2,427,273	2,408,605	2,408,605	2,289,931	2,289,931	2,404,774	2,404,774
PANEL B								
UR months 10 to 12 before birth	0.9963	1.0037	1.0029	0.9971	0.9975	1.0032	0.9954	1.0047
95% Confidence Interval	(0.9915 - 1.0010)	(0.9990 - 1.0085)	(0.9879 - 1.0181)	(0.9822 - 1.0122)	(0.9834 - 1.0119)	(0.9899 - 1.0166)	(0.9882 - 1.0026)	(0.9974 - 1.0119)
P value	0.1260	0.1260	0.7052	0.7052	0.7340	0.6410	0.2064	0.2064
Observations	2,427,273	2,427,273	2,408,605	2,408,605	2,289,931	2,289,931	2,404,774	2,404,774

Note: The table shows the association between the mean local unemployment rate in the months 10 to 18 (Panel A) and 10 to 12 (Panel B) before birth in the city where the mother resided and different maternal characteristics. Standard errors are clustered at the city level. All regressions included fixed effects for mother city of residence, month of birth and year of birth, and two-way interactions between the fixed effects. * p value < 0.1; ** p value < 0.05; *** p value < 0.01.

et al., 2019). Our results suggest that their children are also more vulnerable to in utero exposure to economic downturns.

There are some limitations of our study that should be mentioned. First, the way we constructed the local unemployment rate in the months 1 to 9 before the month of birth introduced some measurement error because we lacked monthly data. Second, as gestational lengths differ from pregnancy to pregnancy, the unemployment rate in the months 1 to 9 before birth might capture periods before conception. This is the case of shorter pregnancies and the local unemployment rate in the months 7 to 9 before birth. For example, for a pregnancy that lasts 7 months, the unemployment rate in the months 7 to 9 is capturing labor market dynamics in moments before conception. This could introduce a downward bias in our estimates for the association between variations in the local unemployment rate during the months 7 to 9 before birth and birth outcomes. If the bias was large enough, we could be wrongly failing to reject the null hypothesis of no association.

An additional limitation is that we cannot conclusively identify a causal path through which in utero exposure to higher unemployment rates results in higher odds of being born with VLBW. The timing of exposure has been used as a proxy to identify the causal path (OLAFSSON, 2016; MARGERISON-ZILKO; LI; LUO, 2017; BOZZOLI; QUINTANA-DOMEQUE, 2014), but there are some concerns about the conclusiveness of that strategy (MARGERISON-ZILKO, 2010; ABU-SAAD; FRASER, 2010). Therefore, the association found deserves further studies to identify the ways through which in utero exposure to economic downturns affects health at birth. Also, the fact that we did not find any association between local unemployment rates at the mother city of residence before conception and maternal characteristics suggests that there is not a selection-into-motherhood effect, but we cannot discard that there is a selection according to unobservable characteristics.

Finally, another limitation is that local unemployment rate dynamics might be capturing changes in another highly correlated variable which could be more relevant. We controlled for month and year fixed effects specific to each municipality of residence of the mother, as well as for an interaction between month and year of birth fixed effects. This allowed us to control for seasonality, yearly changes in other factors, and monthly changes at the national level. However, there might be monthly changes at the local level of variables other than the unemployment rate that could be relevant, e.g. the mean work income or the local level of economic activity.

Despite those limitations, our study shows that there is an association between in utero exposure to higher unemployment rates and worsened birth outcomes, specifically higher odds of being born with very low birthweight when exposure happens during the

last gestational trimester. Exposure affects children born from mothers younger than 24 years old, with less of 11 years of education and black or brown. That means that newborns from women of low socioeconomic status have higher odds of being born very underweight when exposed to economic downturns in the last months of the gestational period. This result calls for further studies on the impact of economic conditions on birth outcomes and on possible buffering mechanisms.

THIRD ESSAY

3 ENVIRONMENTAL DISASTERS AND BIRTH OUTCOMES: IMPACT OF A TAILINGS DAM BREAKAGE IN BRAZIL

3.1 Introduction

3.1.1 Catastrophic events, stress and neonatal health

The relevance of the prenatal environment for fetal development and its long-lasting consequences has attracted attention not only from the biomedical sciences, but also from economics and public health (AIZER; CURRIE, 2014; ALMOND; CURRIE, 2011a; ALMOND; CURRIE; DUQUE, 2018; GLUCKMAN; HANSON, et al., 2008). In relation to this, an important line of research is the relationship between maternal exposure to stress during pregnancy and neonatal health. Bussières et al. (2015) identify different forms used in the literature to measure and conceptualize maternal stress, among them the exposure to natural disasters or other catastrophic events.

The main hypothesized mechanism to explain the relationship between prenatal maternal stress and health at birth is the hypothalamic–pituitary–adrenal axis (HPA axis). When a pregnant woman is exposed to stress, the HPA axis is activated and heightens the levels of cortisol, which in turn leads to higher levels of placental corticotrophinreleasing hormone (CRH). Increased levels of CRH are associated with decreased fetal growth and pre-term delivery (BEIJERS; BUITELAAR; WEERTH, 2014; WADHWA et al., 2004). Even though this mechanism is widely accepted as relevant, it is possible that heightened maternal stress during pregnancy affects birth outcomes also through other mechanisms, like a depressed immune system, which increases the risk of inflammatory reactions that might lead to pre-term birth (BEIJERS; BUITELAAR; WEERTH, 2014; DUNKEL SCHETTER, 2011). Also, higher stress levels might lead to prejudicial habits or health behaviors, like smoking or drinking alcohol, which could also be prejudicial for the newborn (BEIJERS; BUITELAAR; WEERTH, 2014; DUNKEL SCHETTER, 2011; DUNKEL-SCHETTER; LOBEL, 2012).

Maternal exposure to stress during pregnancy may also have long-lasting effects. Some studies have found evidence that health at birth –measured by birthweight or gestational age-is positively correlated with cognitive development, educational outcomes and income in adult life (FIGLIO et al., 2014; BLACK; DEVEREUX; SALVANES, 2007; MOSTER; LIE; MARKESTAD, 2008). There is also evidence of longer lasting effects of stress during pregnancy on children health and educational attainment, independently of any manifestation at birth (KING et al., 2012; AIZER; STROUD; BUKA, 2016)

A frequently studied source of maternal stress is exposure to natural disasters or other kinds of catastrophic events. Following the definition of the United Nation Agency for Disaster Risk Reduction, a disaster can be defined as: "A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts" (UNDRR, 2016). Defining "crisis" in a similar fashion, Vogl and Bharadwaj (2015) highlight three relevant criteria for an event to be defined as such: it must be acute (i.e., not long-lasting), severe (i.e., a large shock that profoundly affects an area) and unexpected (i.e., difficult to anticipate by individuals).

In utero exposure to disasters and related stress have been measured in different forms. Some studies have directly measured stress levels of pregnant women exposed to disasters, either by measuring their levels of cortisol or by applying standardized questionnaires. Other studies have solely considered exposure to a natural disaster or other kind of catastrophic event by the pregnant women place of residence (HARVILLE; XIONG; BUEKENS, 2010).

The first kind of studies can directly assess stress levels and therefore discard other potential mechanisms through which in utero exposure to disasters could be harmful for neonatal health (e.g., TAN et al., 2009; KING et al., 2012; XIONG et al., 2008). However, the second kind of studies usually work with administrative data on whole populations, which gives them an advantage in terms of the unbiasedness and size of the samples they work with (e.g., TORCHE, 2011; TORCHE; SHWED, 2015; TONG; ZOTTI; HSIA, 2011; ESKENAZI et al., 2007; KIM; CARRUTHERS; HARRIS, 2017; QUINTANA-DOMEQUE; RÓDENAS-SERRANO, 2017; CURRIE; ROSSIN-SLATER, 2013; CAMACHO, 2008). That allows them to make stronger causal claims about the effects of exposure to disasters on neonatal health but makes it difficult to disentangle the precise transmission mechanisms.

A limitation of studies on the impact of in utero exposure to catastrophic events on neonatal health is that it is frequently not possible to directly measure maternal stress levels. In those cases, it is difficult to discard other possible causal channels through which disasters could affect health at birth. Specifically, if a large disaster disrupts economic activity, it might generate income reduction or job loss, which in turn could affect birth outcomes. That is a reasonable assumption, as there is evidence of different natural disasters (e.g. earthquakes, different kind of storms, floods) generating significative short-term economic downturns in affected areas, especially in developing countries (KLOMP; VALCKX, 2014; STROBL, 2012; FELBERMAYR; GRÖSCHL, 2014).

There is a large literature about the impact of economic downturns on birth outcomes (e.g., OLAFSSON, 2016; BOZZOLI; QUINTANA-DOMEQUE, 2014; WEHBY;

GIMENEZ; LÓPEZ-CAMELO, 2017; MARGERISON-ZILKO; LI; LUO, 2017). Two mechanisms are usually discussed. On the one hand, financial insecurity might increase maternal stress, which can lead to the same effects described above. On the other hand, there might be an income effect that leads to the reduction in the consumption of health-enhancing products, mainly a nutritionally healthy diet.

The kind of disasters considered in the reviewed studies can be grouped in two different kinds: natural disasters and acute armed violence. Quintana-Domeque and Ródenas-Serrano (2017) analyzed the impact of exposure during pregnancy to a terrorist attack in the mother's province of residence in Spain between 1980 and 2003. Using a database of birth registries in Israel between 2003 and 2009 that includes individual identifiers for the mother, Torche and Shwed (2015) exploited the outburst of the 2006 Second Lebanon War as a natural experiment to assess the effect of prenatal exposure to stress in Israel. Eskenazi et al. (2007) analyzed birth outcomes in areas of New York City not affected by the toxic dust cloud and upstate New York before and after the terrorist attack of 11 September 2001.

All three studies used administrative data on birth records and their results pointed in similar directions. Both Quintana-Domeque and Ródenas-Serrano (2017) and Torche and Shwed (2015) found that exposure to armed violence was related with lower birthweight and a higher prevalence of low birth weight when it occurred during the first trimester of pregnancy. Torche and Shwed (2015) additionally report a negative effect on the duration of pregnancy when exposure happened in any of the first two trimesters. Eskenazi et al. (2007) found that exposure to the stress associated with the events of September 11, 2001, in New York, were associated with increases in low-birth weight when exposure was during the first or second trimester of pregnancy.

Studies on the effects of fetal exposure to natural disasters have focused either in earthquakes (TORCHE, 2011; TAN et al., 2009; KIM; CARRUTHERS; HARRIS, 2017) or different kind of storms: hurricanes (CURRIE; ROSSIN-SLATER, 2013; XIONG et al., 2008), floods (TONG; ZOTTI; HSIA, 2011), and ice storms (KING et al., 2012). The most relevant to us are the ones that make use of large datasets of administrative data on birth records, like our database.

Currie and Rossin-Slater (2013) analyzed the impact of in utero exposure to hurricanes in Texas, USA, between 1996 and 2008, using a mother-fixed-effect model. They found no robust evidence of an impact on birthweight or gestational age but did find robust effects of disaster exposure during the third trimester on the probability of being born with an abnormal condition that originates in the perinatal period (e.g., meconium aspiration syndrome or assisted ventilation)

Torche (2011) evaluates the effects of the 2005 earthquake in Tarapaca, Chile, as a source of maternal stress on birth outcomes and finds a significant effect on birthweight,

gestational age (both negative) and the probability of being born premature (positive), when exposed in utero during the first trimester in the region where the earthquake was more intense. Kim et al. (2017) did a similar exercise with the 1994 Northridge earthquake in Los Angeles, California, in the USA and found a positive, albeit little, effect on the probability of being born with low birthweight. These last two works rely on the unexpected and acute character of the earthquakes to exploit them as natural experiments, using a difference-in-differences methodology.

These studies disentangle the transmission mechanisms from disasters to worsened birth outcomes according to the gestational period of exposure. A similar strategy was followed by some studies on the effects of in utero exposure to economic downturns (OLAFSSON, 2016; BOZZOLI; QUINTANA-DOMEQUE, 2014). Significant effects of in utero exposure to catastrophic events or economic downturns in the first stages of the gestational period are ascribed to the stress channel. Significant effects when exposure was in the last stages of pregnancy are attributed to the nutritional channel. However, there should be concerns about the conclusiveness of that strategy to identify the causal channel linking shocks endured in utero to birth outcomes (MARGERISON-ZILKO, 2010; ABU-SAAD; FRASER, 2010).

The objective of our work is to evaluate if the breakage of a dam containing waste from a mining site in Brazil, in 2015, affected the health of newborns exposed in utero. This event had similar characteristics to other disasters: it was a large shock with a considerable impact on a circumscribable geographical area and was mostly unexpected to residents. However, an interesting difference is that while earthquakes and hurricanes are natural disasters, the Mariana Tragedy was an environmental disaster whose occurrence was responsibility of human actions, and, thus, potentially preventable. The occurrence of a similar disaster involving a tailing dam in the same region in January 2019 highlights the relevance of assessing every possible impact of those events (FREITAS et al., 2019).

Even though there is consensus about the prejudicial effects of exposure to catastrophic events during pregnancy, there is still debate on the most vulnerable periods of the gestational process and the specific birth outcomes affected. Also, considering that the event occurred in a middle-income country, with high poverty rates and low access to care in some regions, the effect of disasters is expectedly higher, because measures aimed at buffering the consequences of exposure are presumably weaker.

3.1.2 The *Mariana Tragedy*

On November 5, 2015, a dam containing mining waste from the *Samarco* mining company in Bento Rodrigues, a district of the Mariana municipality in Minas Gerais, a southeastern Brazilian state, had a breakage. Consequently, a mudflow containing mining waste advanced on parts of four different municipalities, all in Minas Gerais: Mariana,

Barra Longa, Rio Doce, and Santa Cruz do Escalvado. The mudflow reached also the river *Rio Doce* and spread through its waters for approximately 600 km, affecting 34 other municipalities (31 in Minas Gerais and 3 in Espirito Santo, a neighboring state). Due to the magnitude of the event and the extent of the damages, it remained popularly known as the *Mariana Tragedy*.

The report made by the task force organized by the government of Minas Gerais to assess the consequences of the dam breakage divides its effects in two different regions: the four municipalities directly hit by the mudflow and the remaining municipalities, mainly affected by the pollution of the *Rio Doce* water (GRUPO DA FORÇA TAREFA, 2016).

In the four municipalities directly affected, the mudflow caused 19 deaths and 256 injured people. In addition, over 600 people lost their house and 280 suffered related illnesses. Considering also other consequences (e.g. interruption of electricity and water supply, of health care and educational services, and destruction of physical infrastructure), 10,482 of the residents of those four municipalities were considered to have been directly impacted (GRUPO DA FORÇA TAREFA, 2016).

In the municipalities affected by the pollution of the *Rio Doce*, the immediate consequences were linked to restrictions in the availability and quality of water. In 14 municipalities water supply was suspended due to the presence of toxic waste or turbidity above tolerable levels. This did not only temporally impact water for human consumption but also agriculture, fishing, tourism, and celluloid production, i.e., economic activities relevant for the region (FERNANDES et al., 2016; GRUPO DA FORÇA TAREFA, 2016).

While, to our knowledge, no systematic evaluation of the actual impacts of the Mariana Tragedy on economic growth, personal income or private consumption has been undertaken; Simonato, Domingues, and Magalhaes (2018) realized simulations using a computable general equilibrium model. According to their estimations, in the municipality of Mariana, where 87.4% of newborns directly affected in utero come from, the Tragedy resulted in a decrease in private household consumption between 1.22% and 1.74% in the four-year period after the tragedy. Additionally, the Tragedy affected the capacity of providing public services, as up to 80% of local government revenue comes from mining, and interrupted the economic chain of small and middle-sized companies that provide goods and services to mining companies (FREITAS et al., 2019).

3.2 Methods

3.2.1 Data

In order to assess the effect of in utero exposure on birth outcomes, we used the microdata from the SINASC-DATASUS, the System of Information on Life Births from

the Department of Informatics of the Unified Health System, i.e., the Brazilian National Health Service. Each observation corresponds to one live birth and provides information on the pregnancy, newborn, and mother characteristics. Additionally, we used data from the SIM-DATASUS, the System of Information on Mortality, which includes data from all death records, including fetal deaths, to estimate fetal mortality rates. All data from SINASC-DATASUS and SIM-DATASUS are open access and are available online[1].

The SINASC-DATASUS was implemented in 1990 and has steadily increased its coverage and quality of information. Using a conservative methodology comparing populational growth projections and the actual observed count of newborns according to the DATASUS, Szwarcwald et al. (2019) estimated a 94.1% coverage in Minas Gerais and 98.1% in Espírito Santo for the year 2013. Yet, different studies point to the fact that data on fetal deaths is significantly under-reported and that reporting patterns are heterogeneous (BARBEIRO et al., 2015).

Szwarcwald et al. (2019) assessed the quality of information in the SINASC-DATASUS, comparing it with an in-depth survey conducted in a sample of maternity hospitals. The information on weight-related birth outcomes used by us (birthweight and low birthweight) was assessed as having high quality. While gestational age was assessed as having only moderate quality, due to many divergences with the benchmark, identification of premature newborns was assessed as having high quality.

In the SINASC-DATASUS, gestational age is measured according to the last menstrual period. When information on the last menstrual period is not available, the gestational age recorded in the system is estimated either by a physical exam of the newborn or by an "other method" (without specifying which one was used). While the usage of different methods introduces measurement error, there was a high level of enrollment in antenatal care in the observations included in our databases, which is presumably associated with better data quality. In our database, only 0.95% of observations did not have any antenatal care visits, 73,75% had seven or more, 20.91% had between 4 and 6 visits, and 4.04% 1 to 3 visits. Also, as mentioned above, data on preterm birth was assessed as having high quality, which presumably means that inaccuracies in gestational length measurement mostly do not occur around the 37 weeks threshold.

Using data from SINASC-DATASUS, we first selected all births between 2013 and 2016 in the two states affected by the Mariana Tragedy: Minas Gerais and Espírito Santo. Further, we dropped all multiple births (2.4% of total observations), because the interpretation of indicators of neonatal health is different for those cases, and births that occurred outside hospitals (0.5%), in which recorded information is presumably less accurate (n = 1,231,567 births).

[1] `http://datasus.saude.gov.br/transferencia-de-arquivos` (last accessed: 20/02/2020)

To avoid potential selection problems that could arise from reproductive decisions being affected by exposure to the Mariana Tragedy, we limited our sample to births that occurred until July 2016, i.e. the ninth month since the dam breakage. We further dropped all births prior to August 2013, in order to have 3 full years of data (n = 914,795).

We then collapsed all birth data by municipality of residence of the mother and month and year of birth, and we constructed a panel with birth data from all municipalities from the states of Minas Gerais and Espírito Santo. We also counted the number of fetal deaths by municipality of residence of the pregnant women to estimate the fetal deaths rate and added that data to our panel. Our final database consisted of a panel of 36 birth cohorts (from August 2013 to July 2016) from 931 municipalities and included data from live births and fetal deaths.

We used data from reports on the consequences of the Tragedy (GRUPO DA FORÇA TAREFA, 2016) that identify all 38 municipalities directly or indirectly affected: 35 in Minas Gerais (four directly and 31 indirectly) and three in Espirito Santo (all indirectly). We added binary variables indicating if the municipality of residence of the mother was directly or indirectly affected. As the Tragedy might have had an economic impact in some neighboring municipalities (SIMONATO; DOMINGUES; MAGALHAES, 2018), we added a third binary variable for municipalities that pertain to the same *microregion* (i.e., the same geographical area, as defined by the Brazilian Institute of Geography and Statistics) as directly or indirectly affected ones. Figure 3.1 shows the location of affected municipalities, differentiated by the intensity of exposure to the Tragedy.

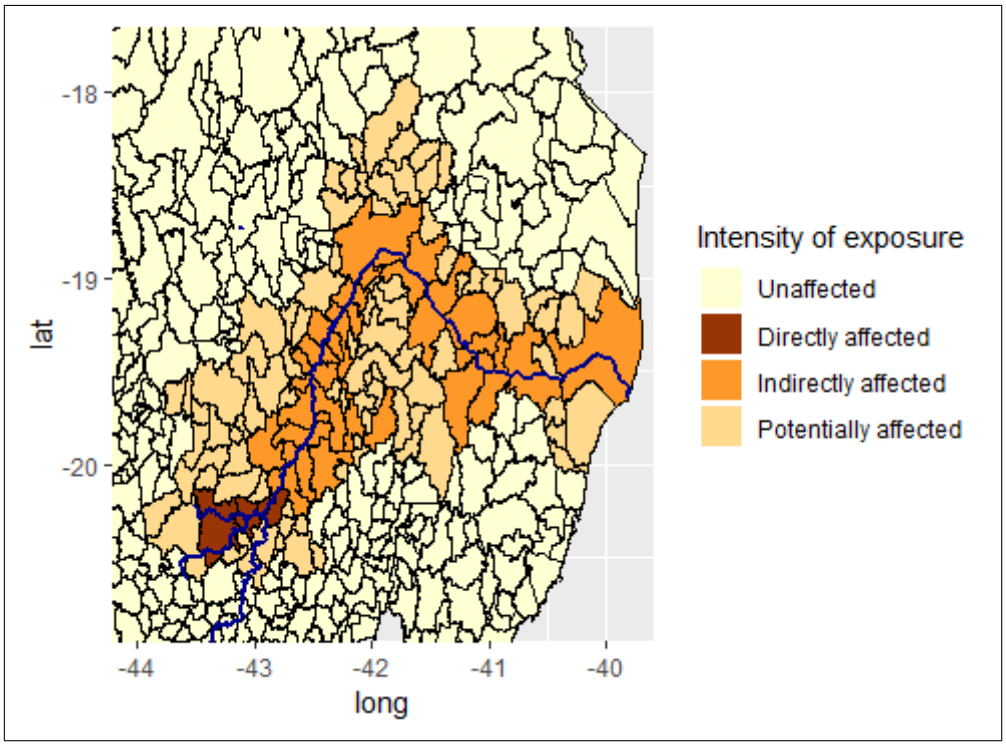
3.2.1.1 Dependent variables

We used data on the following birth outcomes: mean birthweight (in grams), mean gestational age (in weeks), proportion of low birthweight births (LBW, under 2500 g), and preterm births (PTB, less than 37 weeks of gestation). As it is possible that injuries in utero result in miscarriages, we used two different measures to check for this: proportion of male births and fetal deaths rate (fetal deaths per 1000 *potential births*, i.e., live births plus fetal deaths). The proportion of male births is used because there is evidence of a link between stress inducing events and a decline in the proportion of male births, due to selective fetal loss (BRUCKNER; CATALANO, 2018). We also checked if exposure to the Mariana Tragedy affected the number of births, as a way of measuring attrition due to migration.

3.2.1.2 Explanatory variables

We identified all births in affected and neighboring municipalities between November 2015 (the month of the dam breakage) and July 2016 (the ninth month). We considered

Figure 3.1 – Municipalities by intensity of exposure to the *Mariana Tragedy*



Source: author's elaboration with data from the Brazilian Institute of Geography and Statistics (IBGE).
Note: the map does not include all unaffected municipalities.

three different levels of in utero exposure intensity. We adopted the classification of official reports and considered birth in those months in municipalities reached by the mudflow as directly affected and in municipalities near the *Rio Doce* as indirectly affected. We also considered births in those months in proximate municipalities (defined as those in the same *microregion* as a directly or indirectly affected one) as potentially affected because we cannot discard that psychological or material effects of the *Tragedy* were not felt in neighboring cities. We therefore had three binary variables indicating if the newborn was potentially, indirectly or directly in utero affected by the consequences of the dam breakage. Additionally, we differentiated the timing of the exposure to identify if the specific gestational trimester of exposure was relevant.

3.2.1.3 Covariates

In the base specification of our difference-in-differences model, we included fixed effects for municipality of residence, for each month-and-year of birth, i.e., for the 36 birth cohorts, for calendar month of birth and municipality-specific linear trends. In additional specifications we added state-specific year fixed effects and/or maternal characteristics (i.e., percentage of mothers under 20 years old, percentage of black and brown mothers, percentage of single mothers and percentage of mothers with up to 7 years of education).

3.2.2 Estimation strategy

To estimate the impact of the Mariana Tragedy on health at birth, we used a difference-in-differences framework. We estimated regressions of the following form (model 3.1):

$$\begin{aligned} y_{cmt} = \alpha + \beta_1\, directly\_affected_{cmt} + \beta_2\, indirectly\_affected_{cmt} \\ + \beta_3\, potentially\_affected_{cmt} + \gamma_c + \lambda_{mt} + \eta_m + \varphi\, Trend_{cmt} + \varepsilon_{cmt} \end{aligned} \tag{3.1}$$

Where y_{cmt} is one of the dependent variables described above in municipality c, in month m, and year t. $directly\_affected_{cmt}$ indicates cohorts of newborns in municipalities reached by the mudflow between November 2015 and July 2016. $indirectly\_affected_{cmt}$ indicates cohorts of newborns in municipalities next to the *Rio Doce* between November 2015 and July 2016. $potentially\_affected_{cmt}$ indicates cohorts of newborns in that period in municipalities proximate to directly or indirectly affected ones. γ_c is a municipality fixed effect, λ_{mt} is a cohort (i.e, month-and-year of birth) fixed effect, η_m is a calendar-month fixed effect to control for seasonality and $Trend_{cmt}$ is a municipality-specific time trend to allow for possible differences in pre-exposure trends. In additional specifications, we added state-specific year fixed effects. For regressions with birth outcomes as dependent variables, we also added maternal characteristics as covariates.

We also assessed the impact of the different levels of exposure to the *Mariana Tragedy* on birth outcomes according to the gestational trimester of exposure, estimating regressions of the following form, where G represents the gestational trimester of exposure (model 3.2):

$$\begin{aligned} y_{cmt} = \alpha + \sum_{G=1}^{3} \beta_1\, directly\_affected_{cmt} + \sum_{G=1}^{3} \beta_2\, indirectly\_affected_{cmt} \\ + \sum_{G=1}^{3} \beta_3\, potentially\_affected_{cmt} + \gamma_c + \lambda_{mt} + \eta_m + \varphi\, Trend_{cmt} + \varepsilon_{cmt} \end{aligned} \tag{3.2}$$

In all cases, robust standard errors were clustered at the municipality level to account for serial correlation and all regressions were estimated by Ordinary Least Squares, weighted by the municipality average monthly number of births during the whole period.

3.3 Results

The directly affected region is comparatively small, and comprises only one municipality with sizable population, Mariana, which had 58,802 inhabitants in 2015, i.e. 81% of the population living in directly affected municipalities (Table 3.1). The indirectly affected region is considerably bigger and includes two cities with over 250,000 inhabitants in 2015: Ipatinga and Governador Valadares.

Table 3.1 – Unemployment rate before conception and selection into motherhood

	Unaffected	Potentially affected	Indirectly affected	Directly affected
Number of municipalities	806	87	34	4
Number of births	811,526	48,608	51,883	2,778
Population (in 2015)	22,024,656	1,354,009	1,348,143	72,204
Monthly fetal deaths rate	11.4	11.9	10.0	11.0
Mean birthweight	3170	3174	3216	3173
Mean gestational age	38.55	38.56	38.63	38.65
LBW	0.078	0.076	0.068	0.073
PTB	0.100	0.103	0.094	0.096
Male	0.512	0.513	0.514	0.525
Maternal characteristics				
Age <20 years old	0.159	0.162	0.158	0.148
Black or brown	0.618	0.621	0.557	0.610
<8 years of formal education	0.198	0.242	0.208	0.209
Single	0.399	0.336	0.272	0.367

Note: The table shows the data for the whole period (August 2013 July 2016) aggregated by the intensity of exposure to the *Mariana Tragedy* of the municipality of residence of the mother.

Considering the whole period, the incidence of LBW and PTB is lower in the indirectly and directly affected regions when compared to unaffected and potentially affected ones. Mean birthweight and gestational age are also higher. In unaffected municipalities there are proportionally less mothers with less than 8 years of schooling, but more single mothers, than in indirectly or directly affected municipalities. In directly affected municipalities, the proportion of teenage mothers is smaller and in indirectly affected municipalities the fraction of black and brown mothers is smaller than in all other regions.

Table 3.2 shows the results of estimating model 3.1 for four different birth outcomes: birthweight (in grams), gestational age (in weeks), and proportion of the newborns with LBW and PTB. For each dependent variable, the first column shows the results for our base model, the second column for the model adding maternal characteristics and the third column for the model adding also state-specific year fixed effects.

In additional regressions (Table B.1 in appendix), to add robustness to our results, we tried models with yearly socioeconomic data: municipality per capita GDP, per capita local government expenditure with health and social assistance, and per capita expenditure with the *Programa Bolsa Familia* (i.e., the largest federal conditional cash transfer program). The results remained almost identical, which is not surprising given that municipality and year fixed effects had already absorbed most of these effects.

The results show that in utero exposure to the Mariana Tragedy in directly affected municipalities resulted in shorter pregnancies and higher incidence of preterm births. Considering our base model, being directly exposed in utero to the Tragedy resulted in 1.86 days (-0.266×7 days) shorter mean gestational age and, more importantly, 2.6 percentage points higher incidence of preterm birth. Those results are robust to the inclusion of maternal characteristics and state-specific year fixed effects, as well as socioeconomic

Table 3.2 – Estimation of Model 3.1: intensity of in utero exposure and birth outcomes

	Birthweight			Gestational age			LBW			PTB		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
potentially_affected	-7.1769	-7.1880	-8.2135	0.0131	0.0118	0.0129	0.0015	0.0016	0.0018	0.0075	0.0075	0.0080
	(10.3879)	(10.3991)	(10.5419)	(0.0448)	(0.0445)	(0.0445)	(0.0053)	(0.0053)	(0.0053)	(0.0060)	(0.0060)	(0.0061)
indirectly_affected	-0.4951	-0.5203	-0.8187	-0.0458	-0.0487	-0.0488	-0.0051	-0.0049	-0.0049	0.0031	0.0031	0.0031
	(0.9532)	(0.9509)	(0.9237)	(0.1572)	(0.1512)	(0.1467)	(0.3134)	(0.3500)	(0.3438)	(0.6132)	(0.6067)	(0.6058)
directly_affected	-10.1943	-10.1478	-9.9593	-0.2662***	-0.2605***	-0.2584***	-0.0163	-0.0166	-0.0170	0.0264***	0.0263***	0.0258***
	(18.7705)	(18.7775)	(19.1464)	(0.0425)	(0.0426)	(0.0426)	(0.0119)	(0.0119)	(0.0122)	(0.0037)	(0.0037)	(0.0037)
Maternal characteristics	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes
Month fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-specific year fixed effect	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Observations	32,566	32,566	32,566	32,566	32,566	32,566	32,566	32,566	32,566	32,566	32,566	32,566
R-squared	0.2039	0.2039	0.2061	0.2724	0.2731	0.2733	0.0865	0.0866	0.0878	0.1315	0.1317	0.1337

Note: robust standard errors clustered at the municipality level between parentheses. All regressions include municipality of residence of the mother and month-and-year fixed effects, as well as municipality-specific linear trends. Birthweight is measured in grams and gestational age in weeks. LBW: low birthweight ($<$ 2500 grams). PTB: preterm birth ($<$ 37 weeks of gestation). When considered, maternal characteristics are the proportion of mothers: younger than 20 years old, black or brown, less than 8 years of education, single. * p-value $<$ 0.1, ** p-value $<$ 0.05, *** p-value $<$ 0.01.

characteristics of the municipalities, as additional controls in our regression, and in all cases significant at the 1% level.

In utero exposure in those municipalities did not have a significant impact neither on mean birthweight nor on the incidence of LBW, although it is worth noting that the sign of the coefficient for LBW is opposite to the expected one for directly and indirectly affected cohorts. We further analyzed if the coefficient was significant for very low birthweight ($<$ 1500 grams), extremely low birthweight ($<$ 1000 grams) or birthweight between 1500 and 2499 grams (Table B.2). None of the coefficients reached the conventional significance thresholds. The counter-intuitive sign of the LBW of coefficient seems to come from a decrease in the proportion of babies between 1500 and 2499 grams. As this could be indicating an increase in fetal losses affecting babies that would be born under-weighted, we further analyzed that question.

A potential problem when estimating the impact of in utero exposure to some phenomena on birth outcomes is attrition in the affected cohorts. There is evidence that stressful conditions during pregnancy lead to fetal loss, and that they disproportionately affect male fetus. If that were the case in our study, we would have attenuation bias, because there would be missing newborns whose birth outcomes would be presumably worse. To check for this, we used two different measures: fetal deaths rate (number of fetal deaths per 1000 potential births) and the proportion of male births, because there is evidence of selective fetal loss in face of stress inducing events. An additional source of attrition could be maternal migration. If pregnant women residing in affected municipalities moved to other cities as a response to the Tragedy and after delivery the new city was recorded in birth certificates as the city of residence, we would expect the number of births in affected municipalities to decrease.

To check for the existence of those different forms of attrition, we estimated model 1 with number of births, fetal deaths rate and proportion of male births as dependent variables. Table 3.3 shows the results of our estimations. In all cases, we estimated both our base model and a model including state-specific year fixed effects.

According to our results, there is some evidence that in utero exposure to the *Tragedy* in indirectly affected municipalities (i.e., municipalities that are next to the *Rio Doce* but were not reached by the mudflow) led to miscarriages. In those municipalities, the Tragedy resulted in an increase of 4.2 fetal deaths per month per 1000 *potential births* (live births plus fetal deaths). However, as we did not find any effect on the number of births or the proportion of male births, these results should be taken with caution because fetal deaths are likely under-reported and reporting rates might not be uniform among municipalities (BARBEIRO et al., 2015). In potentially and directly affected municipalities, we found no impact of the *Mariana Tragedy* on the number of births, fetal deaths rate

Table 3.3 – Estimation of Model 3.3: intensity of in utero exposure and attrition

	Number of births		Fetal deaths rate		Sex = male	
	(1)	(2)	(3)	(4)	(5)	(6)
potentially_affected	13.9020	13.6473	1.3343	1.3446	0.0049	0.0050
	(8.9998)	(8.6501)	(1.7842)	(1.7753)	(0.0103)	(0.0103)
indirectly_affected	3.7166	3.1224	4.1553***	4.1787***	-0.0013	-0.0010
	(9.7865)	(9.1942)	(1.3076)	(1.3094)	(0.0114)	(0.0112)
directly_affected	10.9999	12.1338	-3.9028	-3.9468	0.0064	0.0058
	(8.9415)	(9.7738)	(3.6665)	(3.6749)	(0.0087)	(0.0087)
Month fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
State-specific year fixed effect	No	Yes	No	Yes	No	Yes
Observations	33,516	33,516	32,594	32,594	32,565	32,565
R-squared	0.9971	0.9971	0.0940	0.0941	0.0584	0.0586

Note: robust standard errors clustered at the municipality level between parentheses. All regressions include municipality of residence of the mother and month-and-year fixed effects, as well as municipality-specific linear trends. Birthrate: number of births per 1000 inhabitants. Fetal deaths rate: number of fetal deaths per 1000 *potential births* (births + fetal deaths). Sex = male: proportion of male newborns. * p-value < 0.1, ** p-value < 0.05, *** p-value < 0.01.

or the proportion of male newborns. We interpret these results as a sign of absence of in utero selection and attrition due to maternal migration.

We further analyzed the relevance of the timing of in utero exposure to the *Mariana Tragedy*. We focused exclusively on gestational age and the incidence of PTB, the two outcomes for which we found an impact considering the whole gestation. The results are shown in Table 3.4. We estimated the same three models as in Table 3.2: our base model and models including state-specific year fixed effects and maternal characteristics. We found that in utero exposure during all gestational trimesters in directly affected municipalities significantly altered gestational age and the incidence of PTB, and the impact was larger when exposure was during the first trimester. Focusing on PTB as outcome and our base model (column 4), we found an impact of 3.6 p.p. on the incidence of PTB among the cohorts exposed during the first trimester. During the second and third trimester the impact was 2.1 and 2.5 percentage points, respectively.

Finally, we realized a series of additional robustness checks. The results are shown in Table 3.5. Columns 1 to 3 shows the results of running the same regressions as in columns 10 to 12 of Table 2 but restricting the sample to municipalities in the state of Minas Gerais (where all directly affected municipalities are). This implied changing the composition of the control group by dropping all observations from the state of Espirito Santo. The coefficients for the impact of in utero exposure to the *Mariana Tragedy* on the incidence of PTB remain basically unchanged when compared to the ones in Table 3.2. Columns 4 and 5 show the results of regressions ran directly from the microdata, without constructing the panel of municipalities, both including and not including maternal characteristics as covariates. The coefficients are somewhat smaller than in Table 3.2 but point in the same direction and remain significant at the 1% threshold.

Table 3.4 – Estimation of Model 3.2: timing and intensity of exposure and gestational age/preterm birth

	Gestational age			PTB		
	(1)	(2)	(3)	(4)	(5)	(6)
potentially_affected_1trim	-0.0229	-0.0244	-0.0225	0.0081	0.0081	0.0086
	(0.0679)	(0.0671)	(0.0664)	(0.0092)	(0.0092)	(0.0092)
indirectly_affected_1trim	-0.0468	-0.0504	-0.0505	0.0042	0.0042	0.0040
	(0.0461)	(0.0448)	(0.0445)	(0.0057)	(0.0057)	(0.0058)
directly_affected_1trim	-0.3975***	-0.3904***	-0.3868***	0.0364***	0.0363***	0.0362***
	(0.0646)	(0.0647)	(0.0655)	(0.0072)	(0.0073)	(0.0070)
potentially_affected_2trim	-0.0178	-0.0204	-0.0194	0.0127*	0.0128*	0.0135**
	(0.0519)	(0.0520)	(0.0519)	(0.0066)	(0.0066)	(0.0067)
indirectly_affected_2trim	-0.0625*	-0.0687**	-0.0690**	0.0038	0.0040	0.0041
	(0.0365)	(0.0326)	(0.0324)	(0.0064)	(0.0066)	(0.0065)
directly_affected_2trim	-0.2848***	-0.2731***	-0.2716***	0.0211***	0.0207***	0.0202***
	(0.0387)	(0.0388)	(0.0389)	(0.0067)	(0.0068)	(0.0068)
potentially_affected_3trim	0.0572	0.0572	0.0578	0.0032	0.0031	0.0034
	(0.0495)	(0.0495)	(0.0498)	(0.0068)	(0.0068)	(0.0068)
indirectly_affected_3trim	-0.0323	-0.0323	-0.0322	0.0019	0.0018	0.0019
	(0.0585)	(0.0583)	(0.0582)	(0.0081)	(0.0080)	(0.0080)
directly_affected_3trim	-0.1787***	-0.1785***	-0.1767***	0.0251***	0.0252***	0.0245***
	(0.0517)	(0.0518)	(0.0510)	(0.0051)	(0.0051)	(0.0054)
Maternal characteristics	No	No	Yes	No	No	Yes
Month fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
State-specific year fixed effect	No	Yes	Yes	No	Yes	Yes
Observations	32,566	32,566	32,566	32,566	32,566	32,566
R-squared	0.2725	0.2732	0.2734	0.1315	0.1317	0.1338

Note: robust standard errors clustered at the municipality level between parentheses. All regressions include municipality of residence of the mother and month-and-year fixed effects, as well as municipality-specific linear trends. Gestational age is measured in weeks. PTB: preterm birth (< 37 weeks of gestation). When considered, maternal characteristics are the proportion of mothers: younger than 20 years old, black or brown, less than 8 years of education, single. * p-value < 0.1, ** p-value < 0.05, *** p-value < 0.01.

Table 3.5 – Impact of in utero exposure to the *Mariana Tragedy* on PTB: robustness checks

	PTB							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
potentially_affected	0.0053	0.0055	0.0055	0.0056	0.0061		0.0073	0.1230
	(0.0073)	(0.0074)	(0.0074)	(0.0046)	(0.0046)		(0.0132)	(0.2277)
indirectly_affected	-0.0041	-0.0039	-0.0039	0.0031	0.0030		0.0043	-0.4549
	(0.0054)	(0.0057)	(0.0057)	(0.0059)	(0.0060)		(0.0102)	(0.7512)
directly_affected	0.0264***	0.0258***	0.0258***	0.0225***	0.0227***		0.0366***	0.5253***
	(0.0037)	(0.0037)	(0.0037)	(0.0046)	(0.0044)		(0.0102)	(0.0380)
potentially_affected_placebo						0.0027	-0.0002	
						(0.0087)	(0.0080)	
indirectly_affected_placebo						0.0056	0.0010	
						(0.0072)	(0.0057)	
directly_affected_placebo						-0.0028	0.0085	
						(0.0084)	(0.0104)	
Maternal characteristics	No	Yes	Yes	No	Yes	No	No	No
Month fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-specific year fixed effect	No	No	Yes	No	No	No	No	No
Interacted with inverse of distance	No	No	No	No	No	No	No	Yes
Observations	29,762	29,762	29,762	914,795	914,795	21,686	32,566	32,566
R-squared	0.1214	0.1233	0.1233	0.0060	0.0085	0.1563	0.1315	0.1314

Note: robust standard errors clustered at the municipality level between parentheses. Columns 1 to 3 include only municipalities in the state of Minas Gerais. Columns 4 and 5 include results from microdata (each birth is one observation) instead of the panel of municipalities. In column 6 the interest variable is a placebo *Tragedy* in November 2014. In column 7, we have both our original interest variables and a lead (a placebo *Tragedy* 9 months before the real one). In column 8, our interest variable are the original ones interacted with the inverse of the distance between the geographical center of the municipality and the broken mining dam. All regressions include municipality of residence of the mother and month-and-year fixed effects, as well as municipality-specific linear trends. PTB: preterm birth (< 37 weeks of gestation). When considered in panel models, maternal characteristics are the proportion of mothers: younger than 20 years old, black or brown, less than 8 years of education, single. When considered in models with microdata are binary variables indicating the age (younger than 20, 20 to 24, 25 to 34, 35 or older), education (less than 8 years, 8 to 11 years, 12 years or more, ignored), race (black, brown, white, indigenous, Asian, ignored), and marital status (single, married, divorced, widow, consensual union, ignored).* p-value < 0.1, ** p-value < 0.05, *** p-value < 0.01.

Additionally, as is common practice when applying the difference in differences methodology, we realized placebo tests. We first dropped all observations posterior to July 2015 and estimated the impact as if the *Mariana Tragedy* had occurred in November 2014 (column 6 of Table 3.5). We did not find any impact of this mock Tragedy. Our second placebo, depicted in column 7, was a lead (i.e. we tested if there was an impact in the 9 months before it happened). This, together with the inclusion of municipality-specific linear trends in all other regressions, is a way of providing credibility to the parallel-trends assumption. Again, the coefficient for the fake exposure was non-significant, which adds credibility to our results.

We realized a similar exercise for all three trimesters before the tragedy. We regressed PTB on a binary variable indicating being subject to the disaster later, considering the three different intensities of exposure as in all other cases. None of the estimated coefficients was significant, which shows no divergence in pre-treatment trends in comparison and treatment groups. Figure 3.2 shows the point estimates and 95% confidence interval of this exercise for births from mothers residing in directly affected municipalities. Figures B.1 and B.2 in the appendix show the same estimations for births from mothers residing in the indirectly and potentially affected municipalities, respectively.

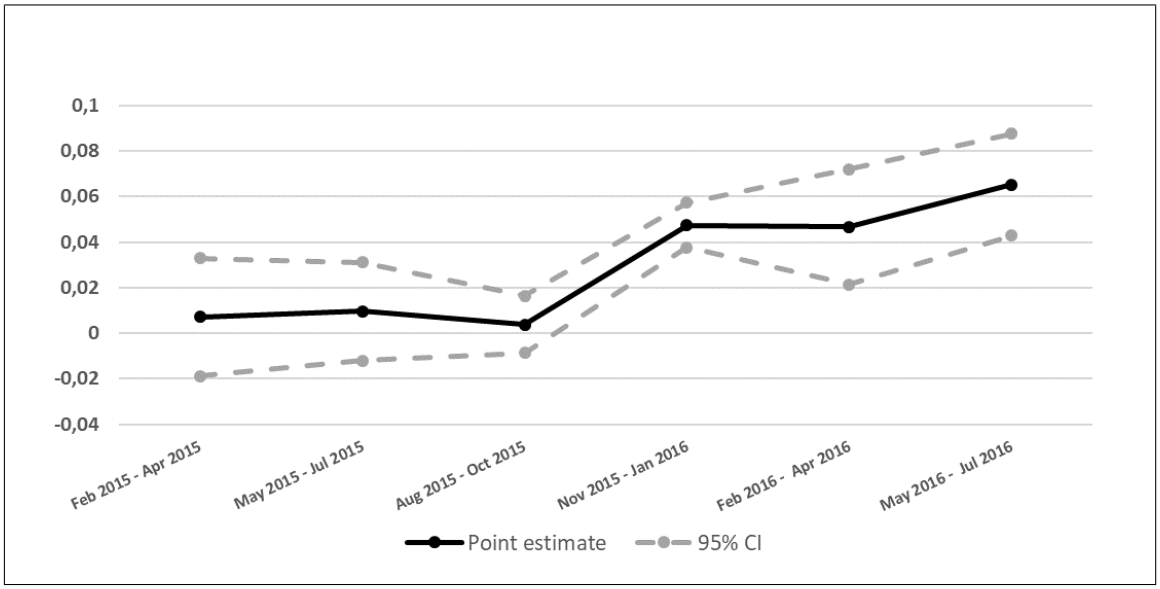
Finally, Column 8 shows the results of adopting as interest variable the interaction between the binary variables indicating the level of in utero exposure and the proximity to the geographical location of the broken dam, measured by the inverse of the distance in kilometers from the geographical center of the city. The impact among newborns exposed in directly affected municipalities is similar to the one without considering the distance. For the municipality of Mariana, with a center located 19.72 km of the dam and where most directly exposed cases are, the 0.525 coefficient implies a 2.7 p.p. increase in the percentage of children born premature, similar to the effect we had previously found.

We did the same robustness checks with the mean gestational age as outcome variable (Table B.3 in the appendix). The robustness of the results for gestational age was in line with the robustness of the results for pre-term birth. Taken together, all these robustness checks increase our confidence in the estimated impact of the *Mariana Tragedy* on prematurity.

3.4 Discussion

We found a significant and large impact of in utero exposure to the *Mariana Tragedy* in directly affected municipalities on mean gestational age at birth and the proportion of preterm newborns. Considering our base model, exposure in those municipalities resulted in gestations around 1.9 days shorter (0.266 weeks) and a 2.64 percentage points higher proportion of premature newborns. The impact was larger among those exposed in the

Figure 3.2 – Differences in pre-treatment trends: births from mothers residing in directly affected municipalities



Note: coefficients and standard errors were obtained from estimation of equations similar to Equation 3.2 but adding also binary variables for being subject to being affected by the disaster later in the three trimesters before exposure.

first three months of gestation (2.79 days shorter gestation and a 3.64 p.p. increase in the proportion of premature babies) than in the second (1.99 days and 2.11 p.p.) or in the third (1.25 days and 2.51 p.p.). These results were robust to the inclusion of different covariates, to the restriction of our sample to births only in the most affected state, and to the use of microdata instead of a panel of data aggregated at the municipality level.

Even though we cannot completely discard migration of pregnant women as a result of exposure to the Tragedy, which seems likely in directly affected municipalities, we found no effect on the number of births, which gives us confidence in our results not being driven by endogenous migration. If there was migration from most affected municipalities to other places, we would expect to see a reduction in the number of births. Additionally, we found no evidence of in utero selection due to fetal deaths in directly affected municipalities. We found an increase of fetal deaths in indirectly affected ones. Even though this result should be interpreted with caution due to problems with reporting of fetal deaths, it could mean that we underestimated the effect in those municipalities if more fragile fetus died in utero.

The results found are in line with previous studies indicating negative impacts of unexpected natural disasters on neonatal health. In our case, we only found those effects for weeks of gestation and preterm delivery, and notably larger in magnitude. Of the two studies most similar to ours, Torche (2011) and Kim, Carruthers, and Harris (2017), only the first one found an effect of in utero exposure to a disaster on gestational age and prematurity. In cities were the intensity of the analyzed earthquake was high, Torche (2011)

found a 0.188 weeks reduction in gestational age and a 2.6 percentage points increased probability of being born premature among newborns affected in utero during the first trimester. She found no impact among those exposed in later trimesters. Additionally, in the context of exposure to acute armed violence, Torche and Shwed (2015) found a reduction of 0.099 weeks of gestation when exposed during the first trimester and of 0.095 when exposed during the second trimester of gestation.

The main limitation of our study, shared by many analyses on the impact of large-scale catastrophic events on neonatal health, is that we cannot directly test for the main hypothesized causal mechanism (i.e., that exposure heightens maternal stress levels, which in turn affects birth outcomes). We showed the existence of an association between in utero exposure to the *Mariana Tragedy* in highly affected municipalities and worse neonatal health, i.e. a higher proportion of premature births. However, it is not possible to state that the causal channel goes exclusively through heightened maternal stress.

Similar previous studies try to disentangle the causal channel by assessing the gestational trimester of exposure for which a significant impact on birth outcomes is found. We found significant effects independently of the trimester of exposure, which could be interpreted as in utero exposure to the Mariana Tragedy having affected birth outcomes through different channels. However, there is evidence that the causal channel identification through the gestational period of exposure might not be appropriate (ABU-SAAD; FRASER, 2010; MARGERISON-ZILKO, 2010).

In fact, it is possible that the higher effect found, when compared to exposure to other natural and non-natural disasters, is due to the presence of more than one channel linking exposure to the *Tragedy* and birth outcomes. According to the official report of the government of Minas Gerais (the state in which all four directly affected municipalities are located), the event did not only cause direct human harm, but had also a significant impact on infrastructure and disrupted economic activity. A study based on simulations using a computable general equilibrium model (SIMONATO; DOMINGUES; MAGALHAES, 2018) estimated a decrease in private consumption between 1.22% and 1.74% due to the *Tragedy* in Mariana, the most affected municipality and where 87.4% of newborns directly affected were born. Even though that is an estimation based on a simulation, and we cannot extrapolate it directly to pregnant women, the magnitude of the impact of the event in directly affected municipalities makes it unlikely that the effect on birth outcomes goes exclusively through heightened maternal stress level due to exposure to the dam breakage. Disruption of local economic activity can be an additional source of maternal stress, but it might also have a negative impact on personal income and reduce the consumption of health-enhancing products. It is therefore likely that our estimates reflect both stress-related and not stress-related channels through which exposure led to worsened birth outcomes.

Despite the difficulties in identifying the causal channel, the magnitude of the association between exposure to the *Mariana Tragedy* and preterm birth highlights the necessity of designing and implementing interventions focused on pregnant women during natural or environmental disasters. Preterm infants are more likely to develop complications early in life (e.g., respiratory conditions, a compromised immune system, cardiovascular disorders), which leads to an increase in the need of medical care services and higher neonatal (under 28 days) and infant (under 1 year) mortality rates (BEHRMAN; BUTLER, 2007). Additionally, preterm birth has been associated with lower wages and educational levels in adult life (MOSTER; LIE; MARKESTAD, 2008).

3.5 Conclusion

We showed that the breakage of a tailings dam in Southeastern Brazil was related with shorter pregnancies and an increase in the proportion of preterm births (< 37 weeks of gestational age) for newborns exposed in utero in municipalities directly affected (i.e., reached by the mudflow). Our results are robust to different model specifications and in line with previous findings about the impacts of catastrophic events on neonatal health but considerably larger, possibly due to the combination of stress-related and not stress-related channels through which exposure led to worsened birth outcomes.

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CONCLUSION

In the first essay of this thesis, we presented two prominent approaches to the relationship between justice and health, namely: Daniels' application of John Rawls' theory of justice to health and the capabilities approach. We saw that in both approaches health can be thought of as an object of justice because it is a key element in the opportunities individuals have to pursue life plans they consider valuable. From those perspectives, all conditions endured in the prenatal period or during childhood that are relevant for human health through the life course, or for the development of other skills or abilities, should be of normative concern.

We also presented empirical evidence, coherent with Heckman's model of capabilities formation, that shows that in utero conditions are important because they can affect neonatal health, and through it outcomes later in life, and because they can have non-mediated long-term impacts on adult life outcomes. However, our two empirical papers only showed the relationship between in-utero environment and birth outcomes, without exploring possible impacts in health early in life or in health or non-health related outcomes later in life. While we cannot empirically answer that question here, we try to present some arguments that highlight the relevance of our results in light of the arguments presented in the first essay.

The results presented in the second essay showed that a 1 percentage point increase in the local unemployment rate in Brazilian state capitals in the trimester before birth was associated with 2.68% higher odds of being born with very low birthweight (VLBW, $<$ 1500 grams). That result was pushed by the effect among newborns from mothers younger than 24 (6.84% higher odds of being born with VLBW), from mothers with 11 years of schooling or less (4.77% higher odds of being born with VLBW), and from brown or black mothers (3.87% higher odds of being born with VLBW).

Having higher odds of being born VLBW is relevant because it is a condition highly associated with neonatal mortality (i.e., mortality during the first 28 days of life). A nationwide, hospital-based, survey of births in Brazil between 2011 and 2012 found that VLBW children accounted for 60.2% of all neonatal deaths, despite accounting for only 1.35% of all live births (LANSKY et al., 2014). While this is not a causal relationship, the magnitude of the association highlights the relevance of VLBW.

While, to our knowledge, there are no causal estimates of the long-term effects of VLBW, evidence from cohort studies shows that it is associated with worse outcomes later in life. For example, a meta-analysis of 34 studies found that being born with very long birthweight and/or very preterm (i.e., $<$ 32 weeks of gestational age at birth)

is associated with higher risks of developing attention-deficit/hyperactivity disorder, a neurodevelopmental disorder associated with lower educational achievement (FRANZ et al., 2018). Additionally, there are cohort studies showing that those birth outcomes are associated with worse mental health, quality of life and cognitive development in early adulthood (ERYIGIT MADZWAMUSE et al., 2015; HUSBY et al., 2016).

The results presented in the third essay showed a large impact of in utero exposure to the Mariana Tragedy in directly affected municipalities on mean gestational age at birth and the proportion of preterm newborns. Exposure in those municipalities resulted in gestations around 1.9 days shorter (0.266 weeks) and a 2.64 percentage points higher proportion of premature newborns.

Prematurity is associated with neonatal mortality. A nationwide, hospital-based, survey of births in Brazil between 2011 and 2012 found that 81.7% of neonatal deaths were from PTB newborns. In 30.3% of cases, prematurity was identified as the main cause of death (LANSKY et al., 2014). Additionally, premature newborns are also more vulnerable to different conditions: respiratory distress syndrome, chronic lung disease, cardiovascular disorders, a compromised immune system, hearing and vision problems and neurological insult (BEHRMAN; BUTLER, 2007).

In the long term, children born preterm are more likely to have worse outcomes. Among children from the 2004 Pelotas cohort study in Brazil, PTB was associated with higher odds of having any psychiatric disorder at age 11 (LA MAISON et al., 2018). Results from a national survey in the United States showed that children aged between 6 and 17 years born preterm were more likely to have different health impairments (cerebral palsy, vision, and hearing problems) than non-preterm children (KODJEBACHEVA; SABO, 2016).

Considering the possible long-term impacts of shocks endured in-utero, affecting the opportunities individuals develop to pursue life plans they value, the question of which policies can alleviate or compensate those impacts is relevant. Preventive policies of care during pregnancy for pregnant women exposed to those shock or compensating policies after birth focused on higher risk children could be relevant tools to buffer the impacts.

The main limitation of our two studies was the impossibility to specify the causal channels through which exposure to adverse environments during the gestational period affects birth outcome. Identifying those channels is an essential pending challenge to specify which kind of policies could be appropriate.

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Appendices

APPENDIX A – APPENDIX TO CHAPTER 2

Table A.1 – False Discovery Rate controlling procedure

Rank	Table	Col.	Independent variable	Dependent variable	p-value	BH p-value	p-value ≤ BH p-value?
1	Table 4	1	UR months 1 to 3 b.b.	VLBW	0	0,0005	yes
2	Table 4	7	UR months 1 to 3 b.b.	VLBW	0	0,0010	yes
3	Table 4	5	UR months 1 to 3 b.b.	VLBW	0,0009	0,0015	yes
4	Table 4	1	UR months 7 to 9 b.b.	VLBW	0,0116	0,0020	no
5	Table 3	6	UR months 1 to 3 b.b.	VLBW	0,0278	0,0025	no
6	Table 2 - B	1	UR months 1 to 3 b.b.	Birthweight	0,0314	0,0030	no
7	Table 3	3	UR months 1 to 3 b.b.	VLBW	0,0372	0,0035	no
8	Table 3	7	UR months 1 to 3 b.b.	Birthweight	0,0382	0,0040	no
9	Table 2 - B	3	UR months 1 to 3 b.b.	VLBW	0,0447	0,0045	no
10	Table 3	4	UR months 1 to 3 b.b.	Birthweight	0,0484	0,0051	no
11	Table 3	9	UR months 1 to 3 b.b.	VLBW	0,0493	0,0056	no
12	Table 3	1	UR months 1 to 3 b.b.	Birthweight	0,0601	0,0061	no
13	Table 2 - B	6	UR months 1 to 3 b.b.	VPTB	0,0613	0,0066	no
14	Table 2 - A	4	UR months 1 to 9 b.b.	Gestational Age	0,0712	0,0071	no
15	Table 4	3	UR months 1 to 3 b.b.	VLBW	0,0965	0,0076	no
16	Table 4	7	UR months 4 to 6 b.b.	VLBW	0,0986	0,0081	no
17	Table 2 - A	6	UR months 1 to 9 b.b.	VPTB	0,1223	0,0086	no
18	Table 5	1	UR months 10 to 12 b.b.	$\leq$ 24 years	0,126	0,0091	no
19	Table 5	2	UR months 10 to 12 b.b.	$\geq$ 25 years	0,126	0,0096	no
20	Table 2 - B	4	UR months 7 to 9 b.b.	Gestational Age	0,1302	0,0101	no
21	Table 4	3	UR months 7 to 9 b.b.	VLBW	0,1338	0,0106	no
22	Table 2 - B	3	UR months 4 to 6 b.b.	VLBW	0,1445	0,0111	no
23	Table 3	9	UR months 4 to 6 b.b.	VLBW	0,1451	0,0116	no
24	Table 4	7	UR months 7 to 9 b.b.	VLBW	0,1528	0,0121	no
25	Table 5	5	UR months 10 to 18 b.b.	Black or brown	0,1646	0,0126	no
26	Table 4	1	UR months 4 to 6 b.b.	VLBW	0,1732	0,0131	no
27	Table 3	3	UR months 4 to 6 b.b.	VLBW	0,1821	0,0136	no
28	Table 4	8	UR months 1 to 3 b.b.	VLBW	0,195	0,0141	no
29	Table 5	7	UR months 10 to 12 b.b.	$\leq$ 11 years of educ.	0,2064	0,0146	no
30	Table 5	8	UR months 10 to 12 b.b.	$\geq$ 12 years of educ.	0,2064	0,0152	no
31	Table 2 - A	1	UR months 1 to 9 b.b.	Birthweight	0,2146	0,0157	no
32	Table 2 - B	6	UR months 7 to 9 b.b.	VPTB	0,222	0,0162	no
33	Table 4	2	UR months 7 to 9 b.b.	VLBW	0,2228	0,0167	no
34	Table 3	6	UR months 4 to 6 b.b.	VLBW	0,2258	0,0172	no
35	Table 2 - B	5	UR months 4 to 6 b.b.	PTB	0,2337	0,0177	no
36	Table 4	4	UR months 4 to 6 b.b.	VLBW	0,2348	0,0182	no
37	Table 2 - B	7	UR months 4 to 6 b.b.	SGA	0,2393	0,0187	no
38	Table 2 - A	7	UR months 1 to 9 b.b.	SGA	0,2482	0,0192	no
39	Table 5	6	UR months 10 to 18 b.b.	White	0,2627	0,0197	no
40	Table 2 - A	2	UR months 1 to 9 b.b.	LBW	0,2749	0,0202	no
41	Table 2 - A	8	UR months 1 to 9 b.b.	Girl	0,2874	0,0207	no
42	Table 4	8	UR months 7 to 9 b.b.	VLBW	0,312	0,0212	no
43	Table 2 - B	5	UR months 7 to 9 b.b.	PTB	0,3215	0,0217	no
44	Table 3	5	UR months 1 to 3 b.b.	LBW	0,342	0,0222	no
45	Table 2 - B	2	UR months 7 to 9 b.b.	LBW	0,3597	0,0227	no
46	Table 3	8	UR months 7 to 9 b.b.	LBW	0,3714	0,0232	no
47	Table 3	2	UR months 1 to 3 b.b.	LBW	0,3909	0,0237	no
48	Table 4	5	UR months 7 to 9 b.b.	VLBW	0,3938	0,0242	no
49	Table 3	3	UR months 7 to 9 b.b.	VLBW	0,4004	0,0247	no
50	Table 4	5	UR months 4 to 6 b.b.	VLBW	0,4036	0,0253	no
51	Table 2 - B	8	UR months 1 to 3 b.b.	Girl	0,4169	0,0258	no
52	Table 4	6	UR months 4 to 6 b.b.	VLBW	0,443	0,0263	no

Table A.1 – False Discovery Rate controlling procedure (cont.)

Rank	Table	Col.	Independent variable	Dependent variable	p-value	BH p-value	p-value ≤ BH p-value?
53	Table 3	9	UR months 7 to 9 b.b.	VLBW	0,4437	0,0268	no
54	Table 2 - B	3	UR months 7 to 9 b.b.	VLBW	0,4468	0,0273	no
55	Table 4	3	UR months 4 to 6 b.b.	VLBW	0,4626	0,0278	no
56	Table 2 - B	1	UR months 7 to 9 b.b.	Birthweight	0,4679	0,0283	no
57	Table 2 - B	7	UR months 1 to 3 b.b.	SGA	0,4725	0,0288	no
58	Table 3	1	UR months 4 to 6 b.b.	Birthweight	0,4873	0,0293	no
59	Table 3	7	UR months 7 to 9 b.b.	Birthweight	0,5005	0,0298	no
60	Table 2 - B	5	UR months 1 to 3 b.b.	PTB	0,5126	0,0303	no
61	Table 3	6	UR months 7 to 9 b.b.	VLBW	0,514	0,0308	no
62	Table 2 - B	4	UR months 4 to 6 b.b.	Gestational Age	0,5424	0,0313	no
63	Table 5	3	UR months 10 to 18 b.b.	Partner	0,5449	0,0318	no
64	Table 5	4	UR months 10 to 18 b.b.	No partner	0,5449	0,0323	no
65	Table 2 - B	4	UR months 1 to 3 b.b.	Gestational Age	0,5553	0,0328	no
66	Table 2 - A	3	UR months 1 to 9 b.b.	VLBW	0,5588	0,0333	no
67	Table 2 - B	2	UR months 1 to 3 b.b.	LBW	0,565	0,0338	no
68	Table 3	1	UR months 7 to 9 b.b.	Birthweight	0,5774	0,0343	no
69	Table 3	8	UR months 1 to 3 b.b.	LBW	0,5806	0,0348	no
70	Table 3	4	UR months 4 to 6 b.b.	Birthweight	0,5898	0,0354	no
71	Table 3	4	UR months 7 to 9 b.b.	Birthweight	0,5927	0,0359	no
72	Table 3	5	UR months 7 to 9 b.b.	LBW	0,5987	0,0364	no
73	Table 4	4	UR months 1 to 3 b.b.	VLBW	0,6049	0,0369	no
74	Table 4	6	UR months 7 to 9 b.b.	VLBW	0,6145	0,0374	no
75	Table 5	1	UR months 10 to 18 b.b.	$\leq$ 24 years	0,6203	0,0379	no
76	Table 5	2	UR months 10 to 18 b.b.	$\geq$ 25 years	0,6203	0,0384	no
77	Table 5	6	UR months 10 to 12 b.b.	White	0,641	0,0389	no
78	Table 2 - A	5	UR months 1 to 9 b.b.	PTB	0,649	0,0394	no
79	Table 2 - B	1	UR months 4 to 6 b.b.	Birthweight	0,6575	0,0399	no
80	Table 3	7	UR months 4 to 6 b.b.	Birthweight	0,6601	0,0404	no
81	Table 4	2	UR months 4 to 6 b.b.	VLBW	0,6635	0,0409	no
82	Table 3	2	UR months 7 to 9 b.b.	LBW	0,6827	0,0414	no
83	Table 5	3	UR months 10 to 12 b.b.	Partner	0,7052	0,0419	no
84	Table 5	4	UR months 10 to 12 b.b.	No partner	0,7052	0,0424	no
85	Table 2 - B	8	UR months 4 to 6 b.b.	Girl	0,7059	0,0429	no
86	Table 5	5	UR months 10 to 12 b.b.	Black or brown	0,734	0,0434	no
87	Table 2 - B	6	UR months 4 to 6 b.b.	VPTB	0,7416	0,0439	no
88	Table 4	8	UR months 4 to 6 b.b.	VLBW	0,7912	0,0444	no
89	Table 2 - B	8	UR months 7 to 9 b.b.	Girl	0,8196	0,0449	no
90	Table 3	8	UR months 4 to 6 b.b.	LBW	0,8443	0,0455	no
91	Table 2 - B	2	UR months 4 to 6 b.b.	LBW	0,8489	0,0460	no
92	Table 3	2	UR months 4 to 6 b.b.	LBW	0,8746	0,0465	no
93	Table 4	6	UR months 1 to 3 b.b.	VLBW	0,8834	0,0470	no
94	Table 2 - B	7	UR months 7 to 9 b.b.	SGA	0,8915	0,0475	no
95	Table 3	5	UR months 4 to 6 b.b.	LBW	0,9084	0,0480	no
96	Table 4	4	UR months 7 to 9 b.b.	VLBW	0,9169	0,0485	no
97	Table 5	7	UR months 10 to 18 b.b.	$\leq$ 11 years of educ.	0,9314	0,0490	no
98	Table 5	8	UR months 10 to 18 b.b.	$\geq$ 12 years of educ.	0,9314	0,0495	no
99	Table 4	2	UR months 1 to 3 b.b.	VLBW	0,965	0,0500	no

Note: BH p-values: correction suggested by Benjamini and Hochberg (1995) considering a False Discovery Rate of 0.05. UR: unemployment rate. b.b: before birth

APPENDIX B – APPENDIX TO CHAPTER 3

Table B.1 – Estimation of Model 3.1: intensity of in utero exposure and birth outcomes. Robustness checks including socioeconomic covariates

	Birthweight			Gestational age			LBW			PTB		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
potentially_affected	-8.3332	-8.3204	-8.3204	0.0161	0.0124	0.0124	0.0019	0.0018	0.0018	0.0079	0.0081	0.0081
	(10.6347)	(10.5505)	(10.5505)	(0.0449)	(0.0448)	(0.0448)	(0.0053)	(0.0053)	(0.0053)	(0.0061)	(0.0061)	(0.0061)
indirectly_affected	-0.2237	-0.8509	-0.8509	-0.0467	-0.0484	-0.0484	-0.0051	-0.0049	-0.0049	0.0029	0.0032	0.0032
	(8.6213)	(8.5519)	(8.5519)	(0.0334)	(0.0335)	(0.0335)	(0.0052)	(0.0052)	(0.0052)	(0.0061)	(0.0061)	(0.0061)
directly_affected	-9.6069	-9.9301	-9.9301	-0.2535***	-0.2533***	-0.2533***	-0.0171	-0.0170	-0.0170	0.0256***	0.0258***	0.0258***
	(19.1753)	(19.1595)	(19.1595)	(0.0432)	(0.0432)	(0.0432)	(0.0122)	(0.0122)	(0.0122)	(0.0037)	(0.0037)	(0.0037)
Maternal characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-specific year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Per capita GDP	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Per capita local government social expenditure	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes
Per capita expenditure with PBF	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No
Observations	31,722	32,566	32,566	31,722	32,566	32,566	31,722	32,566	32,566	31,722	32,566	32,566
R-squared	0.2078	0.2061	0.2061	0.2769	0.2737	0.2737	0.0884	0.0878	0.0878	0.1349	0.1338	0.1338

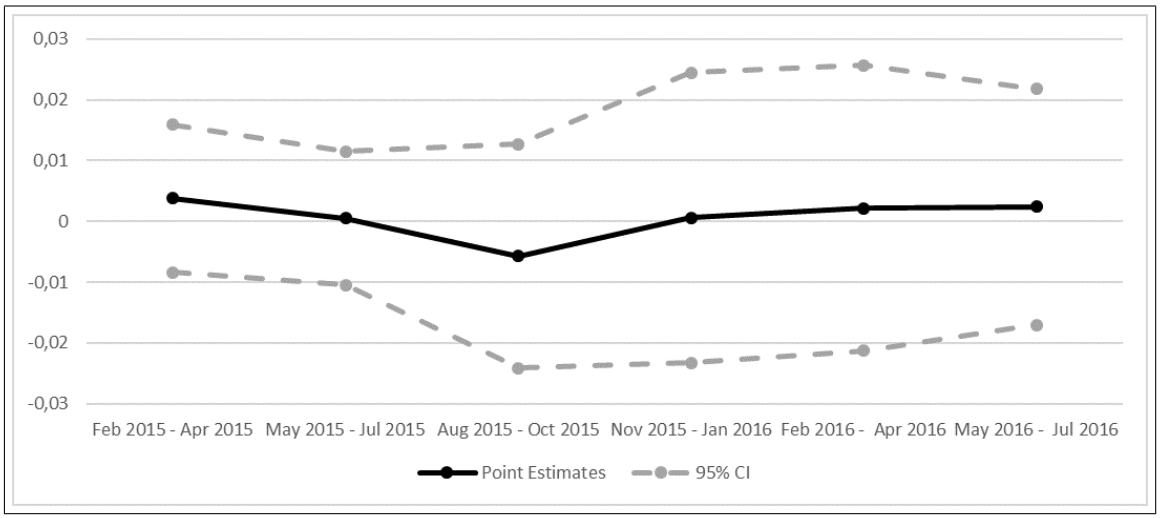
Note: robust standard errors clustered at the municipality level between parentheses. All regressions include municipality of residence of the mother and month-and-year fixed effects, as well as municipality-specific linear trends. Birthweight is measured in grams and gestational age in weeks. LBW: low birthweight (< 2500 grams). PTB: preterm birth (< 37 weeks of gestation). When considered, maternal characteristics are the proportion of mothers: younger than 20 years old, black or brown, less than 8 years of education, single. Per capita local government social expenditure includes expenditure with health and social assistance by the municipal government. Per capita expenditure with PBF (*Programa Bolsa Família*) includes expenditure by the federal government with the largest conditional cash transfer program in Brazil. * p-value < 0.1, ** p-value < 0.05, *** p-value < 0.01.

Table B.2 – Intensity of in utero exposure and VLBW, ELBW and birthweight between 1500 and 2499 grams

	1500 – 2499 grams			VLBW			ELBW		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
potentially_affected	0.0012	0.0015	0.0016	0.0003	0.0003	0.0003	0.0008	0.0008	0.0008
	(0.0046)	(0.0046)	(0.0045)	(0.0024)	(0.0024)	(0.0024)	(0.0014)	(0.0013)	(0.0014)
indirectly_affected	-0.0053	-0.0052	-0.0049	0.0002	0.0002	0.0001	0.0011	0.0010	0.0010
	(0.0046)	(0.0046)	(0.0049)	(0.0013)	(0.0013)	(0.0012)	(0.0010)	(0.0010)	(0.0010)
directly_affected	-0.0173	-0.0173	-0.0178	0.0010	0.0006	0.0008	-0.0010	-0.0014	-0.0013
	(0.0119)	(0.0121)	(0.0121)	(0.0009)	(0.0009)	(0.0009)	(0.0011)	(0.0011)	(0.0011)
Maternal characteristics	No	No	Yes	No	No	Yes	No	No	Yes
Month fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-specific year fixed effect	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Observations	32,566	32,566	32,566	32,566	32,566	32,566	32,566	32,566	32,566
R-squared	0.0820	0.0830	0.0831	0.0663	0.0674	0.0675	0.0634	0.0648	0.0649

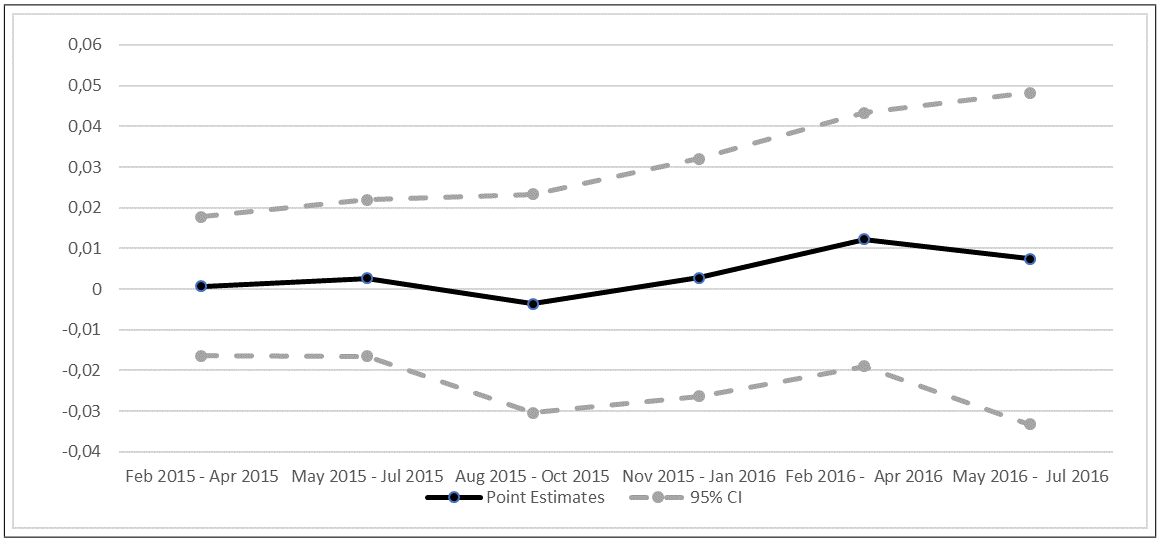
Note: robust standard errors clustered at the municipality level between parentheses. All regressions include municipality of residence of the mother and month-and-year fixed effects, as well as municipality-specific linear trends. VLBW: very low birthweight (< 1500 grams). ELBW: extremely low birthweight (< 1000 grams). When considered, maternal characteristics are the proportion of mothers: younger than 20 years old, black or brown, less than 8 years of education, single. * p-value < 0.1, ** p-value < 0.05, *** p-value < 0.01.

Figure B.1 – Differences in pre-treatment trends: births from mothers residing in indirectly affected municipalities



Note: coefficients and standard errors were obtained from estimation of equations similar to Equation 3.2 but adding also binary variables for being subject to being affected by the disaster later in the three trimesters before exposure.

Figure B.2 – Differences in pre-treatment trends: births from mothers residing in potentially affected municipalities



Note: coefficients and standard errors were obtained from estimation of equations similar to Equation 3.2 but adding also binary variables for being subject to being affected by the disaster later in the three trimesters before exposure.

Table B.3 – Impact of in utero exposure to the *Mariana Tragedy* on mean gestational age: robustness checks

	Gestational age							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
potentially_affected	0.0005	0.0015	0.0015	0.0318	0.0298		0.0035	0.0815
	(0.0537)	(0.0541)	(0.0541)	(0.0353)	(0.0351)		(0.0618)	(1.2351)
indirectly_affected	-0.0295	-0.0296	-0.0296	-0.0475	-0.0431		0.0075	-2.1026
	(0.0381)	(0.0383)	(0.0383)	(0.0310)	(0.0329)		(0.0371)	(5.1841)
directly_affected	-0.2676***	-0.2591***	-0.2591***	-0.2341***	-0.2225***		-0.2981***	-5.6021***
	(0.0428)	(0.0436)	(0.0436)	(0.0331)	(0.0318)		(0.0475)	(0.4236)
potentially_affected_placebo						0.0355	0.0173	
						(0.0515)	(0.0858)	
indirectly_affected_placebo						-0.0514	-0.0368	
						(0.0461)	(0.0459)	
directly_affected_placebo						0.0883	-0.0428	
						(0.0844)	(0.0350)	
Maternal characteristics	No	Yes	Yes	No	Yes	No	No	No
Month fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-specific year fixed effect	No	No	Yes	No	No	No	No	No
Interacted with inverse of distance	No	No	No	No	No	No	No	Yes
Observations	29,762	29,762	29,762	914,795	914,795	21,686	32,566	32,566
R-squared	0.2529	0.2536	0.2536	0.0162	0.0217	0.2986	0.2725	0.2724

Note: robust standard errors clustered at the municipality level between parentheses. Columns 1 to 3 include only municipalities in the state of Minas Gerais. Columns 4 and 5 include results from microdata (each birth is one observation) instead of the panel of municipalities. In column 6 the interest variable is a placebo *Tragedy* in November 2014. In column 7, we have both our original interest variables and a lead (a placebo Tragedy 9 months before the real one). In column 8, our interest variable are the original ones interacted with the inverse of the distance between the geographical center of the municipality and the broken mining dam. All regressions include municipality of residence of the mother and month-and-year fixed effects, as well as municipality-specific linear trends. When considered in panel models, maternal characteristics are the proportion of mothers: younger than 20 years old, black or brown, less than 8 years of education, single. When considered in models with microdata are binary variables indicating the age (younger than 20, 20 to 24, 25 to 34, 35 or older), education (less than 8 years, 8 to 11 years, 12 years or more, ignored), race (black, brown, white, indigenous, Asian, ignored), and marital status (single, married, divorced, widow, consensual union, ignored).* p-value < 0.1, ** p-value < 0.05, *** p-value < 0.01.