The Effects of Sanitation on Infant Health: Evidence from Brazil*

Fernanda Batolla Daniel Da Mata Pedro Oliveira

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Abstract

About 3.4 billion people still lack access to safely managed sanitation, especially in developing countries, posing a threat to public health. More recently, governments in low- and middle-income countries have acted to change this scenario and expand access to piped sanitation. However, there is surprisingly little causal evidence on the consequences of improved sanitation on infant health. This paper studies the effect of in-utero exposure to piped sanitation on birth outcomes. Using linked individual-level and georeferenced administrative datasets from Brazil, we compare pregnant women living under similar infrastructure, other than sanitation, to identify the effects. We show that exposure to piped sanitation increases the birth weight and improves the overall health of newborns. Most vulnerable mothers, however, are less benefited from the expansion of sanitation, highlighting that policies of infrastructure diffusion in developing countries may encounter problems reaching the final user ("last-mile problem"), an issue that policymakers should consider to increase its cost-effectiveness. Altogether, our findings indicate that improving access to piped sanitation is an effective channel to foster neonatal health and generate positive long-run effects on individuals' lives.

JEL Classification: I15, J18, H54, O18

Keywords: sanitation, in utero exposure, birth outcomes, prenatal shocks

*Batolla: fernanda.batolla@fgv.edu.br. Da Mata: Sao Paulo School of Economics - FGV, e-mail: daniel.damata@fgv.br. Oliveira: Sao Palo School of Economics - FGV, email: pedro.costa@fgv.br. We thank the Campo Grande Municipal Health Department and the concessionaire *Águas de Guariroba* for sharing the data with us. Pedro Oliveira gratefully acknowledges financial support from Sao Paulo Research Foundation (FAPESP) Grant #2023/14094-9.

1 Introduction

Low access to safely managed sanitation facilities poses a major threat to public health in several developing countries worldwide. According to the World Health Organization, 3.4 billion people still lack safely managed sanitation as of 2022 (WHO, 2023). These individuals face a greater risk of contamination by infectious and waterborne diseases and have worse nutritional status and overall well-being. Particularly vulnerable to the pervasive effects of the lack of sanitation are the elderly, young children, and pregnant women (and their fetuses). In the last decades, governments of low- and middle-income countries have acted to expand access to sanitation. Yet, there is still little evidence of how these infrastructure improvements affect the most vulnerable groups.

In this paper, we document the impact of an expansion in access to sanitation on health. We do so by studying the expansion of piped sanitation in Campo Grande, a large Brazilian capital. The *Sanear Morena* program increased the city's sanitation services coverage from 22% to 83% between 2006 and 2020. It included expanding the small pre-existing sewage network and building two new sewage treatment stations. Our focus is on infant health for two reasons. First, adults are exposed to various other shocks and are likely to adopt defensive behaviors, making it difficult to disentangle the effects of sanitation (Mouganie et al., 2023). The focus on newborn health is also policy-relevant, given the evidence that the prenatal environment has long-lasting impacts on many aspects of individuals' lives, such as human capital accumulation, adult health, and income (Almond et al., 2005; Black et al., 2007; Almond and Currie, 2011; Shah and Steinberg, 2017).

Prior to 2006, only richer and more central areas of Campo Grande were connected to a piped sanitation network. In the following years, the *Sanear Morena* program heavily increased its access and did so based on criteria related to the hydrological and geological structure of the city's regions. It was implemented quickly to avoid permanent soil contamination. This setting provides a unique opportunity to assess the effects of piped sanitation on infant health.[1] The rapid expansion of the sewage network makes it more likely that women receive piped sanitation during pregnancy, which increases statistical power and allows us to distinguish the effects of sanitation from those related to women's fertility. The expansion program being implemented based on geographic features also enables us to separate the impact of sanitation from other socioeconomic conditions. Lastly, individuals living in the neighborhoods who received piped sanitation through the program are a relatively more vulnerable part

[1] The provision of piped sanitation in Brazil and Campo Grande is discussed in further detail in section 2.1.

of the population.

We combine detailed administrative data on birth records and information on the timing of the implementation of piped sanitation in each place to study the effect of this infrastructure improvement on newborns' health. The richness of our dataset allows us to precisely determine *where* the mothers reside and *when* sanitation was delivered to them during the pregnancy. Our empirical strategy leverages variation in exposure to piped sanitation across mothers living in the same block – and therefore exposed to similar infrastructure other than sanitation. The impact of in-utero exposure to piped sanitation can also be unclear: although positive effects are expected from the biological and medical literature (Kramer, 1987a; Padhi et al., 2015; Patel et al., 2019), the economics literature has shown that this type of infrastructure provision in developing countries often does not have the expected effect, which can be explained by lack of access to complementary services that enhance the impact of sanitation, implementation problems, such as low quality and degradation of the constructed network (Bhalotra et al., 2021; Bancalari, 2024), or issues related to the "last-mile problem" in which the infrastructure does not meet their final users (Ashraf et al., 2016).

Our results indicate large significant effects of in-utero exposure to piped sanitation. Each additional month of exposure to piped sanitation is associated with an increase of about 19.8 grams in birth weight. This effect is large, considering that the average exposure of the women in our sample is nearly five months. This increase is particularly relevant for the lower ends of the birth weight distribution, with a larger reduction in the probability of being born below 2000 grams – near the thresholds considered as low and very low birth weight. Apart from birth weight, we also show an improvement in a health index composed of different indicators of the overall health of the newborn (such as preterm, low birth weight, congenital anomalies, and small for gestational age). These results are matched by an increase in fetal growth rate (defined as the birth weight divided by weeks of pregnancy), but not by an increase in gestational length. We interpret this as suggestive evidence that piped sanitation reduces fetal growth restrictions (Kramer, 1987a,b).

We ask whether the beneficial effect of exposure to piped sanitation is equally distributed among the population, or if a specific group benefits more. To answer this question, we explore the richness of our dataset to conduct heterogeneity analysis. More precisely, we test if children born to more vulnerable mothers benefit more from exposure to piped sanitation. We follow Da Mata and Drugowick (2024) and define the group of more vulnerable mothers as single, younger, and less educated – all of which are characteristics related to a higher probability of unintended pregnancies (Theme-Filha et al., 2016). The results point out that the benefits of exposure to piped sanitation are larger for the *less* vulnerable group, that is older and more educated mothers. We interpret this result in the framework of the "last-mile problem" (Ashraf et al., 2016).[2] Also, we test for differential effects of piped sanitation by trimester of exposure. Regarding birth weight, we find that the effect is driven by exposure in the first and second trimesters, and that being exposed earlier is associated with larger gains. On the other hand, the results for the health index show no significant differences in the effect by trimester. Further results on prenatal care attendance, sex ratio at birth, and infant mortality also show no significant effects.

Our identification relies on the assumption that the implementation of sanitation works is orthogonal to the timing of pregnancy of the women in our sample. We probe the validity of our research design and the robustness of our results in a variety of exercises. We begin showing that the timing of delivery of sanitation works is not strongly correlated with a series of observable characteristics of the mothers. We do find a marginally significant correlation with mothers' age, suggesting that younger women were exposed earlier, but the effect is small. We argue that, if anything, this correlation would push our estimates toward zero, since the existing evidence shows that younger mothers are more likely to have adverse birth outcomes. Next, we also show that the timing of pregnancy is not relevant to the implementation of sanitation works. Crucially, we follow a strand of the literature that compares siblings to account for any unobservable characteristic of mothers that may affect newborns' health (Currie et al., 2022; Da Mata et al., 2023), and estimate the effect of exposure to piped sanitation on birth weight of older unexposed siblings, born before sanitation was made available. We find small and statistically insignificant effects, indicating that the characteristics of the mothers do not drive our results. We probe our results in several other exercises. Overall, the results are robust to the inclusion of various control variables, adding block and neighborhood time trends, dropping specific blocks and periods of our sample, and alternative clustering schemes. We confirm that the main findings do not arise by chance in a placebo exercise, where we randomize the length of exposure to the treatment. Virtually all the placebo effects are smaller than the actual estimates. Taken together, these findings provide strong support for the validity of our research design and the causal interpretation of the exposure to piped sanitation on infant health.

This paper contributes to the growing literature on the effects of infrastructure projects in developing countries. In particular, we contribute to the literature examining the impacts of sanitation infrastructure on health. Previous work has focused on

[2] As discussed earlier, the "last-mile problem" is related to the inability of the infrastructure to reach the final user. This issue, common in developing countries, happens when the private willingness to pay for an infrastructure service is smaller than its average cost and institutions are not strong enough to enforce its adoption. We further discuss how this may occur in our setting in section 5.2.

the experience of developed countries (Kesztenbaum and Rosenthal, 2017; Alsan and Goldin, 2019). However, more recent investigation has shown that these results can not be directly transposed to the scenario of nowadays developing countries (Bhalotra et al., 2021; Bancalari, 2024). Even recent studies for low- and middle-income countries, focus on the lower ends of the sanitation distribution (e.g. open defecation) (Geruso and Spears, 2018; Coffey et al., 2018), which is a highly different context from what we study. On top of that, most existing evidence comes from policy or bureaucratic reforms, rather than the infrastructure construction *per se* (Galiani et al., 2005). A notable exception is Bancalari (2024), which exploits the expansion of public sewerage in Peru past the National Sanitation Plan and shows an increase in mortality rates for infants and under-five. Surprisingly, none of the previous works has examined how sanitation may affect infant health. Thus, we contribute to this literature by providing the first, to our knowledge, investigation of the causal effects of piped sanitation on health at birth, a highly relevant outcome with long-lasting impacts on various aspects of individuals' lives, such as human capital accumulation and adult health (Almond and Currie, 2011).

This paper also adds to the large and growing literature on the effects of prenatal shocks on birth outcomes. This strand has largely focused on "one-off" shocks, such as violence (Koppensteiner and Manacorda, 2016; Currie et al., 2022), diseases (Koppensteiner and Menezes, 2024), and pollution (Mouganie et al., 2023). Another front examines the effect of cash transfers and other welfare programs (Almond et al., 2011; Hoynes et al., 2011; Amarante et al., 2016; Da Mata et al., 2023). Despite the aforementioned relationship between sanitation and health, existing studies are mostly correlational and the causal effects of piped sanitation on birth outcomes remain remarkably scarce. We complement this literature by providing evidence on how improved sanitation infrastructure in the context of a large developing country affects neonatal health. In this sense, our study is closely related to Cameron et al. (2021), which examines the relationship between water and sanitation during pregnancy and pregnancy outcomes in Indonesia. However, they only examine the impact of the probability of low birth weight, as the authors' center of attention is maternal health instead of the newborns. Their analyses reveal no significant effect on the newborns' health, but a strong and significant effect of sanitation on maternal health. We differ from their work in several ways. The richness of our data enables us to separate the effects of sanitation from those related to maternal health and fertility. We also explore a wide range of birth outcomes, which allows us to inform about the effects of sanitation at the average and distinct points of the birth weight distribution, the timing of the effects, and the differential impacts for distinct socioeconomic strata of the population.

Our results are relevant to both health and public policy. The literature has largely documented the long-lasting effects of prenatal and early childhood conditions on later life outcomes (Almond et al., 2011, 2018). There are known long-run impacts on adult health, schooling, and wages (Black et al., 2007; Figlio et al., 2014; Bharadwaj et al., 2018). Back-of-the-envelope calculations reveal that the net gain is positive when the pregnant woman was exposed for the entire pregnancy, representing a gain in birth weight of 178 grams. Besides, to the extent that we measure the effects only on infant health and positive effects are expected in other relevant outcomes, the potential benefits of sanitation are likely overlooked. Hence, our results also inform about an important channel of public policy that aims to improve the health of individuals.

The remainder of this paper is organized as follows. Section 2 describes some detail on the institutional background of sanitation in Brazil and the potential channels of impact of sanitation in infant health. Section 3 describes the data and our sample selection. In section 4 we discuss the research design and empirical strategy. Section 5 presents the main results, heterogeneity exercises, and robustness checks. We conclude in section 6.

2 Background

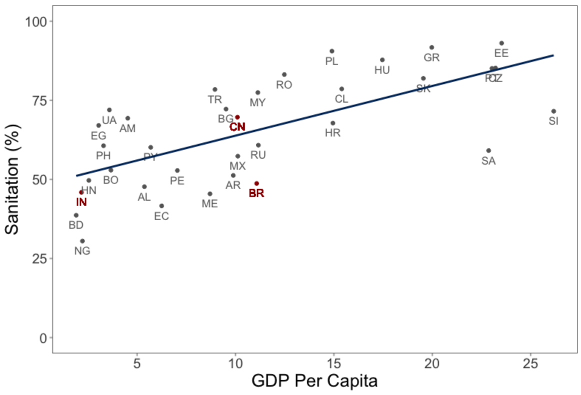
2.1 Sanitation in Brazil

Brazil has a precarious sanitation infrastructure compared to other countries with similar per capita income. Figure 1 shows the percentage of the population that uses improved sanitation facilities, measured by the Joint Monitoring Programme (henceforth JMP), and the GDP per capita, measured by the IMF, for several countries.[3,4] According to JMP, the use of an improved sanitation facility is a proxy for the use of basic sanitation. Considering this indicator, Brazil serves 48% of its population, far behind China, a country with a similar per capita income, and is close to India, with a much lower per capita income. As shown by the linear regression line, a country with Brazil's per capita income should present this indicator at a level of 60%.

[3]An improved sanitation facility hygienically separates human excreta from human contact. It considers a piped sewage system, septic tank, and latrines. It does not consider sanitation facilities shared with other families or open to public use. It also considers the transportation, treatment, and disposal of sanitary waste. Thus, the indicator is a weighted average of the different sewage collection and treatment types.

[4]The WHO/UNICEF Joint Monitoring Program for Water Supply, Sanitation, and Hygiene (WASH) has reported country estimates of progress in this area since 2000. This sanitation classification, from most precarious to most hygienic, has five categories: open defecation, unimproved, limited, basic, and safely managed.

Figure 1: Sanitation and GDP per capita by Countries (2019)



Notes: The graph shows the percentage of the population served with basic sanitation considering the concept of "safely managed sanitation" calculated by JPM and the GDP per capita in in dollars calculated by the IMF for several countries for 2019.

By 2022, only 56% of the population was served by a public piped sewage network, meaning that practically one in two Brazilians did not have access to proper sewage collection (SNIS, 2023).[5] However, regions have significant heterogeneity (see Appendix Figure A.1). While the North and Northeast regions have indicators well below the national average, the Southeast is moving towards universalization. The delay in the provision of sanitation infrastructure resulted from the fragility of the regulatory framework and low public and private investment. Appendix B.1 provides an overview of the sector's regulation and the main factors determining the low investment.

Both municipalities and states are responsible for providing sanitation services in Brazil (Kresch, 2020). Despite the sector's poor performance in recent decades, some cities have been thriving, emerging from a low level and implementing rapid expansion of piped sanitation. Appendix Table A.1 shows the evolution of this service for the 27 state capitals between 2005 and 2019. Particularly successful in this task was the city Campo Grande, which managed to increase piped sanitation by more than 60 percentage points.

In fact, Campo Grande makes an interesting case, since hydrological issues determined the sanitation expansion schedule. Campo Grande has the largest underground aquifer in South America, the Guarani Aquifer.[6] According to the city Municipal Basic Sanitation Plan of 2013 (Prefeitura Municipal de Campo Grande, 2013), areas in "regions with outcropping groundwater" should receive priority service under the risk of

[5]The *Sistema Nacional de Informações sobre Saneamento - SNIS* is an essential data source on the Brazilian sanitation sector, managed by the National Secretary of Basic Sanitation. Its annual database by municipalities has information since 1995. The water and sanitation companies provide the information. Compliance with the SNIS is a condition for accessing federal resources to invest in sanitation, and the information provided is audited.

[6]This formation's main characteristic is permeability, which results in contact between surface and underground waters.

irreversible soil contamination. This is because the land in these areas, which did not have piped sanitation, had severe problems with septic tanks, which also overflowed on rainy days, turning into open sewage.

Campo Grande is the capital of Mato Grosso do Sul, in the midwest region. It has 898 thousand inhabitants and a population density of 111 inhabitants/km^2. Its economy is based on the tertiary sector, emphasizing public administration, commerce, tourism (the Pantanal route), and logistics. Agriculture is also relevant, based on the cultivation of soybeans, corn, rice, wheat, aipim, and livestock. The city's HDI is 0.784 (high), and the Gini index is 0.572.

Regarding basic sanitation, the city hall granted the service in 2000. According to Delmon (2010), the concession model adopted can be considered a Public-Private Partnership (PPP) with the following characteristics: i) business: existing; ii) construction obligation: build; iii) private funding: finance; iv) service delivery: user; and v) source of revenues: tariffs. Initially, the concession contract determined that the system should serve 50% of the population in 2010, 60% in 2021, and 70% in 2026. However, the goals were renegotiated between the city hall and the concessionaire to enable access for 90% of the population until 2025 through the *Sanear Morena* Program, which was carried out in three stages.

Launched in 2006, the Sanear Morena 1 Program (2006-08) increased sanitation services from 22% to 56% and built the Los Angeles Treatment Plant (ETE). Sanear Morena 2, which ran from 2008 to 2013, increased sanitation services to 70% and built the Imbirussu ETE (Prefeitura Municipal de Campo Grande, 2013). In the last stage, Sanear Morena 3, which runs from 2014 to 2025, should universalize service and expand the two ETEs mentioned above. In the first two phases, more than 800 kilometers of sewage collection network were built, with a further 2000 kilometers planned by the end of the program in 2025.

Before the Program, only high- and medium-socioeconomic neighborhoods in the city center had piped sanitation. The remaining neighborhoods used septic tanks – 70% of households used a rudimentary septic tank system, and another 10% used the traditional septic tank system – or unsanitary methods (such as discharging sewage into streams or the street).[7]

2.2 Potential Impacts of Sanitation on Infant Health

This study investigates how a city-wide piped sanitation intervention affects neonatal health. It is, therefore, an urban environment where most houses already have treated water and a bathroom. Even considering that a large portion of households

[7] Figures on the use of septic tanks were obtained from the 2000 Brazilian Demographic Census.

use septic tanks, they have problems. Septic tanks can overflow on rainy days, and turn into open sewage. Septic tanks require a strenuous cleaning routine, which can generate costs for the resident (Deutschmann et al., 2021). The septic tank can lead to the resident having to save water or install more than one tank per residence, depending on the number of residents. Appendix B.2 provides evidence of the inconvenience and harm that septic tanks cause to residents. Therefore, the sanitation infrastructure intervention we study should affect human health through impacts on feco-oral transmitted diseases, worms whose contamination occurs through contact with the skin, and intestinal infectious diseases.[8]

A particular group of people affected by these diseases is pregnant women. Pregnancy is a physiological condition in which hormones and other factors associated with them modulate the woman's immune system to prevent rejection of the fetus. This situation is associated with decreased immunity and increased risk of parasitic infections (Adegnika et al., 2007; Tsoka-Gwegweni and Ntombela, 2014; Lovisa et al., 2016; Buchala et al., 2022). Pregnancy is also associated with increasing demand for nutrients for a rise in maternal blood volume.

Intestinal parasites interfere with the absorption of nutrients as they compete for food and cause hypersensitivity, reducing the time available for digestion and absorption (Tsoka-Gwegweni and Ntombela, 2014). The effects can be diarrhea, anemia (due to iron, folic acid, and vitamin B12 deficiency), and malnutrition (Brooker et al., 2008; Getachew et al., 2012; Wekesa et al., 2014; Coffey et al., 2018).

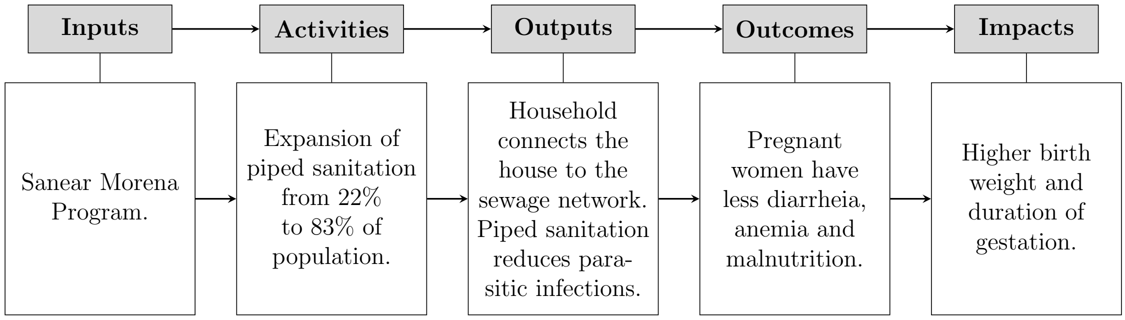
Iron deficiency is the leading cause of anemia during pregnancy, which can affect the growth of the fetus and placenta, impair the transport of oxygen to cells, and the maintenance of the immune system (Goswami et al., 2014; Pereira et al., 2019). Given the increased blood volume during pregnancy, it is necessary to ingest large amounts of iron.

Anemia can also be caused by a lack of folic acid and vitamin B12, two nutrients necessary to produce red blood cells (Coffey et al., 2018). In the fetus, folic acid is the most important factor that reduces the risk of neural tube defects (Thame et al., 1998; Mahmood, 2014; Pereira et al., 2019). Vitamin B12 works together with folic acid, helping with its absorption and playing an essential role in the functioning of the nervous system and the production of the baby's red blood cells. Folic acid is also crucial for preventing premature placental displacement (Pereira et al., 2019).

Prenatal care can alleviate the problem of anemia for pregnant women. In Brazil, the Public Health Network (SUS) offers universal prenatal care, following the WHO

[8]Specifically, i) non-bacterial feco-oral diseases: enterovirus, amoebiasis, giardiasis, and hepatitis A; ii) bacterial feco-oral diseases: cholera and E.coli; and iii) soil helminths: hookworm, strongyloidiasis, ascariasis (roundworm) and trichuriasis. We do not consider water-borne infections.

Figure 2: Theory of Change



Notes: This framework represents how the significant expansion of piped sanitation can affect birth weight and duration of gestation. Piped sanitation reduces parasitic infections and, consequently, cases of anemia in pregnant women. Despite its availability, many pregnant women do not attend all prenatal consultations.

recommendation that at least six consultations be carried out.[9] Consultations must take place as soon as the pregnancy is identified. Folic acid supplementation begins at the first prenatal consultation, and ferrous sulfate supplementation starts at the 20th week of pregnancy. Tests to measure hemoglobin and detect anemia are performed. In the case of moderate anemia, the following is requested: a) parasitological examination of feces and treatment of parasites, if present; b) treatment of anemia, tripling the dose of ferrous sulfate (Schirmer et al., 2000).

However, many pregnant women do not attend all prenatal consultations (Mehra, 2010; Viellas et al., 2014; Anjos and Boing, 2016). The low attendance at prenatal consultations is more common among women with low education, low-income level, pregnant teenagers, those with high parity, and those who live without a partner.[10]

Thus, we hypothesize that poor sanitation (absence of piped sanitation) favors parasitic infections that cause anemia, and pregnant women are more susceptible to these infections, even with prenatal care available in the SUS. Considering the theory of change[11], Figure 2 shows the chain of results of the Sanear Morena Program:

[9] In 2000, SUS launched the Prenatal and Birth Humanization Program to guarantee the quality of prenatal care and birth assistance. This policy was reinforced and expanded in 2011 with Rede Cegonha.

[10] According to Viellas et al. (2014), the leading causes for not having a prenatal consultation are: not knowing you were pregnant, financial restrictions, personal problems (unwanted pregnancy, lack of knowledge about the importance of prenatal care, contingencies related to work/school, and lack of support to attend the appointment), and access barriers (delay in scheduling the appointment, problems with scheduling and difficulty in transportation).

[11] The Theory of Change describes the causal logic of how an intervention can generate the intended results. It reports how a sequence of inputs, activities, and outputs interact with behavior to establish pathways to achieve impacts. For more details, see Imas and Rist (2009) and Gertler et al. (2016).

2.3 Behavioral Effects

A threat to our hypothesis is that the expansion of piped sanitation to the pregnant woman's residence occurs, but it does not connect the house to the sewage network (Stepping, 2016; Kresch et al., 2023) or takes a long time to make the connection (Gertler and Yoshida, 2020). The main reasons are the connection cost and the monthly service bill (BRASIL, 2018), since this population is low-income.

After implementing the collection network, the resident must pay a connection fee (which can be divided into 36 installments) and a tariff that is 70% of the value of the water. The social tariff can be requested for the low-income population, reducing the cost of the monthly bill by up to 50%.[12] In Campo Grande, in 2019, 7% of connected homes had the social tariff. The literature shows no consensus on the willingness to pay for this type of service (Devoto et al., 2012; Deutschmann et al., 2021; Kresch et al., 2023).

Furthermore, improved sanitation projects in developing countries are generally linked to hygiene promotion campaigns, which raises the question of whether any effect on health is attributable to the Sanear Morena Program or hygiene behavior. In Campo Grande's case, as most individuals already have treated water and a built bathroom, the educational campaign focused on adhesion to piped sanitation and the correct system use, and less on hygiene issues.

Implementing piped sanitation may also make individuals more concerned about their health. Individuals can adopt healthier habits like drinking more water or eating healthier. To measure this effect, it would have been necessary to apply questionnaires, which were not carried out.

In particular, it may be that pregnant women who received sanitation attend more prenatal consultations, reducing the chance of anemia. In this case, it would be difficult to identify whether it was an effect of the program or an impact on the more significant number of prenatal consultations. In section 5.3, we investigate this behavior change. Our data points in the opposite direction: pregnant women who receive sanitation tend to have fewer prenatal consultations. One explanation would be that with the arrival of sanitation, pregnant women understand that they have reduced the risk of contracting parasitic infections due to episodes of open sewage.

On the other hand, positive decision spillovers from piped sanitation may occur (Barreto et al., 2007; Kresch et al., 2020; Deutschmann et al., 2021). The fact that the residence already has a bathroom installed reduces the domestic benefit of piped

[12] In Brazil, a legal provision requires the user to connect if there is a network, such as Article 45 of the National Basic Sanitation Law. Moreover, in the concession contract, the city hall also must require connection to the households. But this procedure is not used. The city hall prefers to act through permanent health education campaigns and social tariffs.

sanitation, but septic tanks increase fecal contamination in the neighborhood. The greater the adherence to piped sanitation (deactivation of septic tanks), the more significant the reduction in fecal contamination (Barreto et al., 2007). As the neighborhood becomes cleaner, it may be worth it for residents to have the piped sanitation (Deutschmann et al., 2021). Barreto et al. (2007) found a 22% decrease in diarrhea due to the neighborhood's exchange of septic tanks for piped sanitation. According to Kresch et al. (2020), this positive spillover decision from piped sanitation can be called a multiplier effect or social multiplier.

3 Data and Sample Selection

We gather individual-level administrative data from four different data sources to study the effect of piped sanitation on infant health in Campo Grande. The first is the sanitation expansion map provided by the concessionaire *Águas de Guariroba*. This map contains detailed geolocation of the works carried out between 2006 and 2020 and the date (month and year) each work was delivered. Campo Grande is made up of 1,026 census tracts, which we refer to as blocks. A work comprises several blocks; sometimes, these blocks are divided between two or more works.

Second, we use data on birth records from the Ministry of Health collected through the System of Information on Live Births (SINASC), over the period between 2007 and 2019. This data contains detailed information on the pregnancy, newborns, and mothers. We use the following information about the newborn: birth weight in grams, date of birth, newborn sex, and APGAR score[13], whether they have any congenital anomalies, and parity order (whether it is the first child or not). From the information on pregnancy, we use the number of prenatal consultations (grouped in four categories: 0, 1-3, 4-6, and more than 7), the date of the last menstrual period, the duration of the pregnancy in weeks, the type of birth (natural or c-section), the type of pregnancy (single or multiple), and the hospital where the birth occurred. Additionally, we use information on the mother's age, marital status (single, married, widowed, and divorced), educational level (grouped into four categories: 0-3, 4-7, 8-11, and 12 or more years of schooling), and job occupation.

We use the richness of our data to set the starting and ending points of pregnancy. We define the beginning of pregnancy as the date of conception, which we calculate using either the date of the last menstrual period when available, or subtracting the actual number of weeks of gestation from the date of delivery. As we only have information about sanitation works at the monthly level, we use discrete months and

[13] The APGAR score measures the vitality of the newborn immediately after birth, measured after two minutes and after five minutes.

set the expected full-term childbirth date by adding 9 months to the conception date. Thus, a full-term pregnancy spans 10 different months. Intuitively, by setting the endpoint at 9 months after conception, we let the gestation length be unrelated to the potential influence of piped sanitation.[14]

Information about the mother's exact address is crucial to determine whether a child was exposed to piped sanitation during the pregnancy. We have access to a confidential version of the SINASC data, containing information on the exact addresses of the mothers. We geocode the mother's address using the Google Maps API and restrict our sample to only women residing in the urban region of Campo Grande.

Using the mothers' geocoded address we are able to precisely determine their block of residence and to which, if any, sanitation works they were exposed first.[15] Our sample is composed of any pair of mother-child i that received access to piped sanitation during the pregnancy. Precisely, let p denote the month and year of conception, then our sample is given by:

$$S = \{i : \mathbf{1}\left[p \leq \text{Sanitation} \leq p + 9\right] = 1\}$$

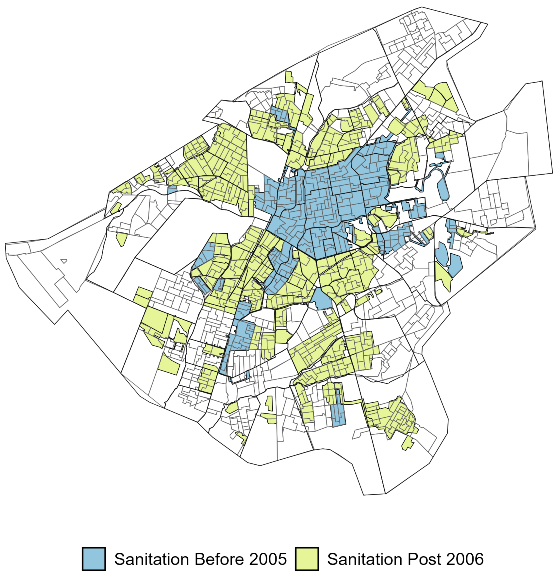
Our sample does not include mothers who received sanitation facilities *before* the conception date (that is, Sanitation $< p$) to avoid account for fertility-related effects and endogenous pregnancies. We excluded from our sample women who gave birth in Campo Grande but do not reside in the city. In addition, we also remove from the sample multiple pregnancies. After these restrictions, we end up with a sample of 3,665 pregnant women over the period 2007-2018. Panels (a) and (b) of Figure 3 show the expansion of the sanitation coverage in Campo between 2006 and 2020 and the location of mothers in our sample, respectively. Green areas in panel (a) show blocks that received sanitation after 2006. In panel (b) one can note that mothers are roughly evenly distributed across these blocks.

We focus mainly on two health outcomes of newborns: birth weight in grams and a health index. The health index is constructed based on the literature that relates sanitation to birth weight, premature births, intrauterine fetal growth, and even factors related to congenital anomalies. We build this index as a Z-score that combines (i) an indicator for preterm birth (< 37 weeks), (ii) an indicator for low birth weight ($< 2,500$ grams); (iii) an indicator that equals one if the newborn was small for gestational age (below the 10th percentile of birth weight according to the weeks of pregnancy), and (iv) an indicator that equals one if the newborn has a congenital

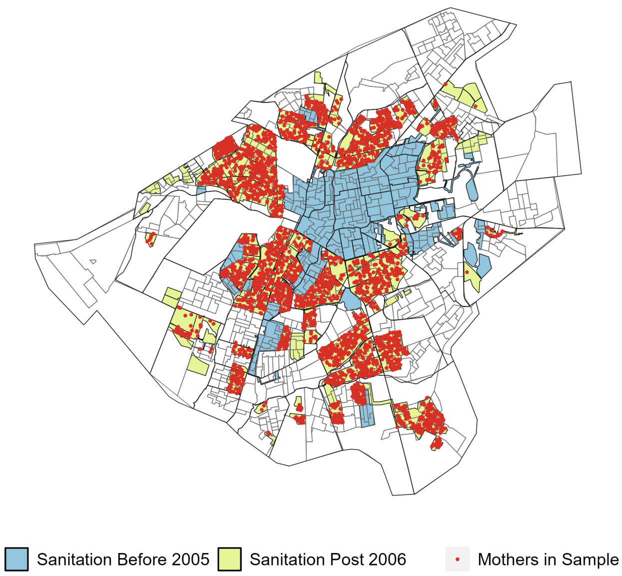
[14]Several papers take this approach to address possible endogeneities in the actual date of birth. See, for instance, Black et al. (2016), Currie et al. (2022), Da Mata et al. (2023), Koppensteiner and Menezes (2024).

[15]It is possible that a mother was exposed to more than one work at different periods. In these cases, we consider the earliest date.

Figure 3: Sanitation Expansion Map and Location of Individuals in our Sample



(a) Map of Expansion of the Sanitation Coverage (2006-2020)



(b) Location of Mothers in our Sample

Notes: Panels (a) and (b) show the expansion of the sanitation coverage in Campo Grande between 2006 and 2020 and the location of the 3,665 mothers in our sample, respectively.

anomaly.[16,17] We reversed the sign of the index so that a positive number implies a better health index. The use of the health index also overcomes the problem of multiple hypothesis testing as it combines the individual dependent variables in one index and then conducts a single test of the association between this index and the key explanatory variables. In this case, the probability of a false rejection does not increase as additional outcomes are added to the summary index (Anderson, 2008). Combining all the outcome measures also has the advantage of increasing the power of the test of association as it simultaneously exploits the variation in all outcome measures. The results are interpreted as whether the explanatory variables have a "general effect" on pregnancy risk.

We complement our data with information from two additional datasets: (i) vital statistics death records from the Mortality Information System (SIM); and (ii) hospitalization records from the Hospital Information System (SIH). The SIM contains information on all natural and unnatural deaths, specifying the cause of death and the characteristics of the deceased. In case of death occurring up to one year of age, the SIM records the characteristics of the mothers and birth outcomes, thus allowing us to link birth records with information on infant mortality. The SIH records all publicly funded hospital admissions at the individual level, including information on individuals' zip code of residence, duration of stay, cost and type of hospitalization, and the primary causes of hospitalization based on the WHO International Classification of Diseases (ICD-10).

4 Empirical Strategy

We aim to estimate the effect of in-utero exposure to piped sanitation on infant health. To this end, we leverage the variation in the timing of the delivery of sanitation works and the fact that women received access to piped sanitation at different stages of their pregnancies. Women in earlier stages of pregnancy were exposed to piped sanitation for more months. The identification assumption is that when piped sanitation is made available in a location, pregnant women are exposed to it regardless of the timing of their pregnancies. Our strategy is to compare women living in the same block, living under similar infrastructure, but exposed to piped sanitation at different stages of their pregnancy. As gestational length may be affected by sanitation, we assign

[16] Small for gestational age is defined as being below the 10th percentile of birth weight according to the gestational age. Although it can not be used as a direct marker for fetal growth restriction, both are often associated (Schlaudecker et al., 2017).

[17] Congenital anomalies exclude chromosomal congenital anomalies.

exposure based on a full-term gestation (9 months after the conception date).[18] We compute the total months of exposure as the difference between the expected month of birth at full-term and the month, within the pregnancy length, in which the mothers first received access to piped sanitation.

Formally, our main specification takes the following form:

$$Y_{ipb} = \alpha + \beta \cdot \textit{Months of Exposure}_{ipb} + \tau_p + \mu_b + \mathbf{X'}_i\gamma + \varepsilon_{ipb} \qquad (1)$$

where Y_{ipb} is one of our health outcomes of interest for child i (e.g. Birth Weight, Health Index), conceived in period p and whose mother reside in block b. The main right-hand side variable, $\textit{Months of Exposure}_{ipb}$, measures how many months child i was exposed in utero to piped sanitation. $\mathbf{X'}_i$ is a vector of covariates, including mothers' socioeconomic characteristics, such as indicators for the mother's age, marital status, highest educational attainment, and characteristics of the pregnancy, as the newborn sex, and indicators for parity order and hospital birth. τ_p and μ_b stand for the period of conception and block fixed effects, respectively. ε_{ipb} is the idiosyncratic error term, which we cluster at the block level in all regressions.

Importantly, block fixed effects control for any time-invariant characteristics of the block, such as socioeconomic status, topographic and geographic characteristics related to sanitation availability, as well as other types of urban infrastructure. Block fixed effects together with our fine-grained definition of the block of residence allow us to remove any variation related to the place of residence of mothers. Month-year (linear and calendar) of conception fixed effects correct for potential seasonality in births and other aggregate shocks common across all the blocks. Thus, we exploit the within-block variation in exposure across mothers to estimate the effect of exposure to piped sanitation on birth outcomes.

Our identification relies on the assumption that, conditional on covariates and fixed effects, the timing of the delivery of sanitation works is orthogonal to the gestational stage of pregnant women. We argue that this hypothesis is likely to hold, since the roll-out of sanitation works was planned *before* our sample period and depends mainly on the geological characteristics of each region. The fact that pregnant women were not a priority group by any means and they represent only a small portion of beneficiaries also speaks in favor of our empirical strategy.[19] Also, observe that as we do not have the exact information on whether mothers are connected to the piped sanitation network, our estimates should be interpreted as intention-to-treat (ITT) effects.

[18] We calculate the expected month of birth of each child at full-term as $t + 9$, where t denotes the month of conception (Currie et al., 2022). We used discrete months due to data limitations. A full-term pregnancy of 40 weeks spans 10 different months.

[19] Despite a population of nearly 900 thousand inhabitants, we only find 3,665 women treated during their pregnancies.

Additionally, we use our data to partially test the plausibility of this assumption. In Table 1 we estimate the correlation between *Months of Exposure* to piped sanitation and observable characteristics of mothers. We present the estimates of this test following the main specification in Equation (1). We only find significant differences in column (3) regarding the mother's age. This difference remains marginally significant once we add controls, in column (4). This may suggest that younger mothers were exposed to sanitation works earlier in their pregnancies. However, the age difference between more and less exposed mothers is small. Each additional month of exposure to piped sanitation is associated with the mother being between 0.14 and 0.10 years younger at birth. Considering the median length of exposure in our sample, this would imply that more exposed mothers are about 5 to 6 months younger, which is unlikely to be driving our results. Conversely, we also use all the covariates in $\mathbf{X'}_i$ to predict the months of exposure. None of the coefficients are statistically significant, and the p-value from an F-test of joint significance of these regressors is 0.99.

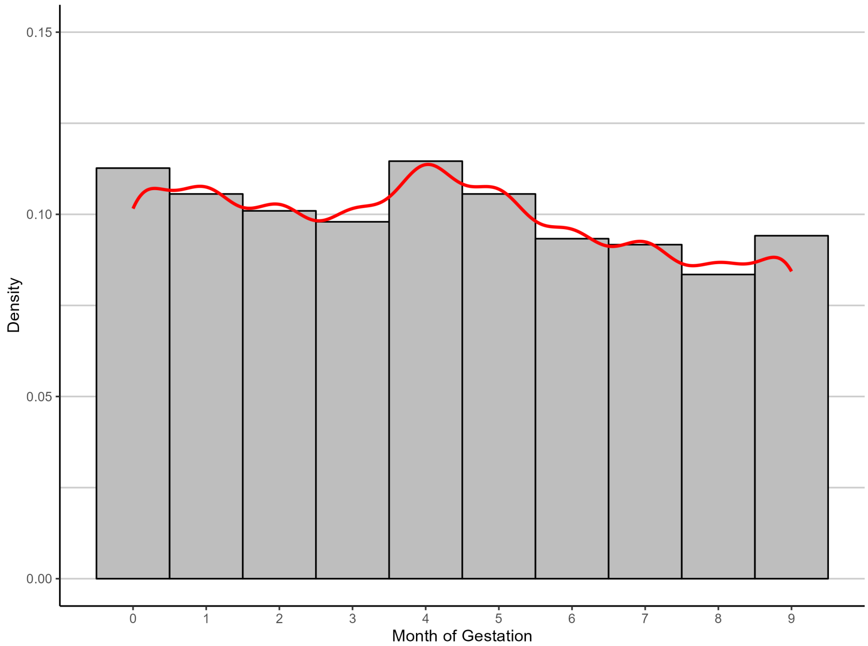
Table 1: Exposure to Sanitation and Mother's characteristics - Balance Test

	FE		FE + Controls	
	Coef.	R^2	Coef.	R^2
	(1)	(2)	(3)	(4)
Mother's Age	-0.145**	0.1764	-0.100*	0.4397
	(0.072)		(0.058)	
High-educated mother	-0.003	0.2307	-0.001	0.3458
	(0.004)		(0.004)	
Single Mother	0.006	0.1835	0.003	0.3131
	(0.006)		(0.005)	
1st Parity	0.000	0.1814	-0.003	0.3748
	(0.007)		(0.006)	
Born in Hospital	0.000	0.1636	0.000	0.1784
	(0.001)		(0.001)	

Notes: This table presents the correlation between the months of exposure to piped sanitation and the mother's characteristics used as controls in our main specification. Columns (1) and (2) report the estimated coefficients and the R^2 of the regression including the fixed effects described in Equation 1. Columns (3) and (4) report the coefficients and the R^2 after adding the control variables. Standard errors are clustered at the block level. *** Significant at 1%, ** Significant at 5%, * Significant at 10%.

Another concern is that women are receiving access to piped sanitation at a certain point in their pregnancies. If that were the case, we would expect to observe clusters of

Figure 4: Histogram of Exposure to Sanitation by Month of Pregnancy



Notes: This histogram shows the frequency of exposure to piped sanitation by month of pregnancy for the mothers in our sample. 0 indicates that a mother were exposed to sanitation in the first month of pregnancy, while 9 indicate exposure in the last month.

mothers exposed to sanitation facilities in a particular month of pregnancy. We inspect this possibility in Figure 4. The histogram presents the frequency of mothers exposed to sanitation works according to the months of gestation.[20] We find no indication of any correlation between the timing of pregnancy and the number of women being exposed to sanitation works, as the distribution is quite similar along the months of gestation.

We address remaining concerns regarding selection by following the approach of Oster (2019) to examine how much selection in unobservables is necessary to explain away our results. To take into account that regions are differentially exposed to environmental risks, which may be related to piped sanitation effects, we also estimate more satiated models, including neighborhood-specific time trends, and block-specific time trends as robustness checks.

Finally, we are also interested in understanding the timing of the effects of sanitation on infant health outcomes, which may be relevant for policy reasons. To this end, we estimate a modified version of Equation (1) separating the full-term gestation period into trimesters. Precisely, we assign children to exposure in the first trimester

[20]Note that, as we are using discrete months, the month of gestation is 0 for those children who received access to piped sanitation in their conception month (thus being exposed to piped sanitation during the whole pregnancy) and 9 for those who are exposed to sanitation works in the expected month of birth.

of pregnancy if the mother received access to sanitation until the third month of pregnancy, the second trimester between the fourth and sixth month, and the last trimester from the seventh month onward. In this exercise, our specification takes the following form:

$$Y_{ipb} = \alpha + \beta_1 \cdot \text{1st Trimester}_{ipb} + \beta_2 \cdot \text{2nd Trimester}_{ipb} + \tau_p + \mu_b + \mathbf{X'}_i\gamma + \varepsilon_{ipb} \quad (2)$$

We include two indicators, for exposure in the first and second trimesters, and estimate the effects relative to exposure in the third trimester of pregnancy.

5 Results

5.1 Main results

We begin by examining the effect of sanitation on birth weight, estimating Equation (1), in Table 2. Odd-numbered columns present the coefficients of specifications including only month-year and block fixed effects. In contrast, even-numbered columns display the results for the specification with the full set of controls. Columns (1) and (2) show that each additional month of exposure to piped sanitation in the intrauterine environment is associated with an increase in birth weight by between 18 to 19 grams. These effects are sizeable and represent an increase in birth weight of about 0.6%. Estimates on the log of birth weight are very similar and indicate an increase of 0.7%. Including controls marginally increases the effect, and both point estimates, in the specifications with and without controls, are significant at 1%.

To gauge the size of the effects, we compare our results with previous findings in the literature. Overall, the point estimates indicate an effect that is larger in magnitude than the effect of other social welfare programs. For instance, Amarante et al. (2016) finds that receiving a conditional cash transfer program in Uruguay increases birth weight by about 30 grams, while Almond et al. (2011) and Hoynes et al. (2011) documents estimates for two distinct nutrition programs ranging between 13 to 42 grams. Specifically for Brazil, Da Mata et al. (2023) shows that in-utero exposure to a climate adaptation policy in the country's driest region increases birth weight by roughly 46 grams. Multiplying our point estimate of 19.85 grams by 4.70 months (the average duration of exposure in our sample) we find a 93.3 increase in birth weight. This effect is also comparable in size to the negative effects of *in-utero* exposure to open-air waste burning Mouganie et al. (2023).

Having established the relationship between sanitation and birth weight, we then ask two further questions: *(i)* what factors are mediating this relationship; and *(ii)* for which part of the birth weight distribution this effect is more relevant. For the first question, the literature usually relates birth weight variations to either the duration

Table 2: Effects of Sanitation Exposure on Birth Outcomes

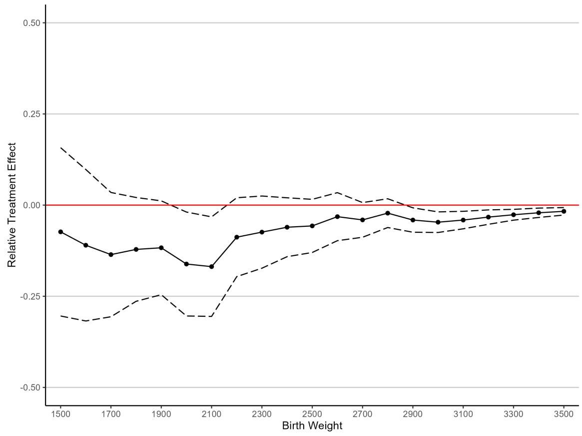
Dependent variables:	Birth Weight		ln(Birth Weight)		Weeks of Gestation		Fetal Growth Rate	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Months of Exposure	18.402***	19.853***	0.007***	0.007***	0.038*	0.041*	0.411***	0.445***
	(5.675)	(5.680)	(0.002)	(0.002)	(0.023)	(0.023)	(0.130)	(0.130)
Block Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes	No	Yes	No	Yes
Dependent variable mean	3,177.97	3,177.97	8.05	8.05	38.50	38.50	82.37	82.37
Observations	3,657	3,657	3,657	3,657	3,657	3,657	3,657	3,657

Notes: This table presents the results of estimating Equation (1) on different birth outcomes. The odd-numbered columns present results without controls, while even-numbered columns present the results controlling for: the mother's age, highest schooling level achieved, marital status, the newborn's gender, parity order, and indicators for the hospital of birth. All columns include month-year of conception and block of residence fixed effects. Robust standard errors (in parenthesis) are clustered at the block level. *** Significant at 1%, ** Significant at 5%, * Significant at 10%.

of gestation or the intrauterine growth rate (Kramer, 1987b; Almond et al., 2005). We investigate these two potential drivers in columns (5) to (8) of Table 2. Columns (5) and (6) show small significant effects of exposure to piped sanitation on weeks of gestation. Each additional month exposed to sanitation facilities is related to an increase of 0.04 weeks in the pregnancy length. In turn, columns (7) and (8) display an increase in fetal growth rate, defined as the birth weight divided by the number of weeks of gestation. Each additional month of access to piped sanitation seems to increase the fetal growth ratio by between 0.445 grams. Considering the average duration of exposure in our sample, we find an increase in the fetal growth rate of 2,09 grams per week. These results are supportive to the mechanism discussed by Kramer (1987a), who argues that interventions related to sanitation in developing countries should affect birth weight mainly through increased intrauterine growth rate.

Next, to investigate the effect of piped sanitation on different points of the distribution of birth weight, we follow Almond et al. (2011) and estimate a series of models on the probability that birth weight is below a given threshold. Specifically, we consider the thresholds between 1500 and 3500g in 100-gram steps. Figure 5 plots the relative effects, that is, point estimates divided by the mean of the dependent variable. The impact is larger in the lower ends of the birth weight distribution and becomes smaller as we move to the right in the birth weight distribution, reaching nearly zero for birth weight below 3500 grams. Note that the point estimates are significant at 5% only for the probability of birth weight in the interval between 1900 and 2200 grams, which are the thresholds indicating low birth weight. For instance, the estimates suggest that each additional month of exposure to piped sanitation in-utero reduces the probability of birth weight below 2100 by approximately 17% and of birth weight below 2500 by approximately 5,7% (although this last one is not statistically significant). These effects are considerably large, but they are not unheard of. González and Trommlerová (2022) examines the effects of a cash transfer program on birth outcomes in Spain, and finds effects of similar magnitudes on the probability of low and very low birth weight. Furthermore, even though the effects on distinct points of the birth weight distribution are imprecisely estimated, probably due to the low frequency of these weights in our sample, they suggest that sanitation has larger positive impacts at the bottom of the distribution. This result is policy-relevant, since children born at the lower end of the birth weight distribution usually experience long-lasting health and developmental difficulties, and impose higher costs on society (Almond et al., 2005; Black et al., 2007). Appendix Table A.2 presents the coefficients of the 21 regressions we used to build the relative effects in Figure 5.

Figure 5: Effects of Sanitation on the Distribution of Birth Weight



Notes: Estimates are obtained using the specification in Equation (1). The figure shows the estimated relative impacts of each additional month of exposure to sanitation in utero on the probability of the birth weight being below a given threshold. We consider 21 distinct thresholds, varying between 1500 and 3500 grams in 100-gram steps. The solid line plots the relative effects (that is, point estimates relative to the mean), and the dashed lines represent the 90% confidence interval.

We now move to examine the effect of sanitation on the health index. Recall that this index is a Z-score composed of the probability of low birth weight, pre-term birth, congenital anomalies, and being small for gestational age. The results of this exercise are displayed in Table 3. Column (1) and (2) shows that piped sanitation has a positive and significant effect on the health index. Each additional month of exposure to piped sanitation in the intrauterine environment increases the health index by approximately 0.014 standard deviations. Considering the average exposure in our sample, piped sanitation would represent an increase in the health index of roughly 0,07 standard deviations. This effect is larger than the effect of a smoking ban policy in Brazil (Da Mata and Drugowick, 2024), the negative effects of petroleum leaks (Marcus, 2021), and similar in magnitude to the negative effect of violence exposure (Currie et al., 2022). We interpret this result as evidence that exposure to piped sanitation in the intrauterine environment improves the overall newborn's health. In columns (2) to (10) we investigate the effect of sanitation in each component of the health index separately. Despite all point estimates being negative – indicating that each additional month of exposure reduces the likelihood of adverse birth outcomes –, we only find significant effects on the probability of being born small for gestational age. Columns (9) and (10) show that each additional month of exposure to piped sanitation reduces the probability of being small for gestational age by 0.5 percentage points. Considering the average length of exposure in our sample, this would imply a reduction of 2.35% or roughly 26% of the mean incidence. These results point toward a mechanism of reduction in intrauterine growth restrictions, which reinforces our findings of Table 2. The coefficients of the remaining components of the health index are imprecisely estimated probably due to the low frequency of these events in our sample.

Table 3: Effects of Sanitation Exposure on Health Index

Dependent variables:	Health Index		Pre Term (< 37 weeks)		Low BW (<2,500 grams)		Congenital Anomaly		Small for Gest. Age	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Months of Exposure	0.012	0.014*	-0.003	-0.004	-0.004	-0.004	-0.001	-0.001	-0.005	-0.005*
	(0.008)	(0.008)	(0.004)	(0.004)	(0.003)	(0.003)	(0.001)	(0.001)	(0.003)	(0.003)
Block Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Dependent variable mean	0.01	0.01	0.09	0.09	0.07	0.07	0.00	0.00	0.09	0.09
Observations	3,657	3,657	3,657	3,657	3,657	3,657	3,657	3,657	3,657	3,657

Notes: This table presents the results of estimating Equation (1) on different birth outcomes. The odd-numbered columns present results without controls, while even-numbered columns present the results controlling for: the mother's age, highest schooling level achieved, marital status, the newborn's gender, parity order, and indicators for the hospital of birth. All columns include month-year of conception and block of residence fixed effects. Robust standard errors (in parenthesis) are clustered at the block level. *** Significant at 1%, ** Significant at 5%, * Significant at 10%.

5.2 Heterogeneous effects

We have documented significant positive effects of piped sanitation on infant health. These average effects, however, can vary substantially according to the characteristics of the mothers or the place where they live. In this subsection, we investigate this possibility and ask whether the effect of piped sanitation is more relevant to some specific groups. To this end, we split our sample according to information on the mothers' age, marital status, and educational attainment. It is well-established in the medical literature that maternal age is an essential determinant of birth outcomes and, alongside marital status, can be an indicator of vulnerability (Fraser et al., 1995; Shah et al., 2011). In turn, education can proxy for income, which is also regarded in the literature as a relevant determinant of birth weight (Kramer, 1987a).

In Table 4 we explore possible heterogeneous effects of exposure to piped sanitation on birth weight. We start examining differences according to the mothers' age. In columns (1) and (2) we split our sample into two age groups: the first group comprises mothers up to 24 years old, which we referred to as younger mothers; the second group includes mothers aged 25 or more. Results suggest that children born to mothers in the older age group benefit more from exposure to piped sanitation. The point estimate suggests that each additional month of exposure increases the birth weight of this group by 26.7 grams, an increase of approximately 0.8% of the group mean. The effect is smaller for mothers in the younger age group and not statistically significant. Columns (3) and (4) display the results according to the mother's educational attainment. We define mothers as less educated if they have up to seven years of formal education and highly educated if they have eight or more years of formal education. Results indicate that exposure to piped sanitation was more beneficial to children born to mothers with higher education. For this group, we estimate an impact of 19.6 grams per additional month of exposure. Finally, we split the sample according to the mothers' marital status. In this case, we classify mothers as single or non-single. The results in columns (5) and (6) indicate significant effects for children born to mothers in both groups. However, the point estimate in column (6) indicates that sanitation was more beneficial to children of non-single mothers. The estimated effect indicates that, for the group of non-single mothers, each additional month of exposure increases birth weight by roughly 30 grams, while the increase for single mothers is about 22 grams.

Table 5 depicts a similar analysis, using the health index as the outcome instead. Overall, we observe a similar pattern to that observed in birth weight. The estimated coefficients suggest larger effects for children born to older and more schooled mothers (columns (2) and (4), respectively). Unlike the result for birth weight, columns (5) and (6) show a positive and marginally significant effect of exposure to piped sanitation for children born to single mothers. The coefficient in column (2) indicates that each additional month of exposure leads to an increase of 0.02 standard deviations in the health index for children of mothers over 24 years old. Column (4) shows that each additional month of exposure to sanitation increases the health index for children of more educated mothers by 0.017 standard deviations. The point estimate for low-educated mothers is small in magnitude and imprecisely estimated. Regarding mothers' marital status, we find an increase of 0.02 for children of single mothers for each additional month of exposure.

Taken together, our results indicate that the impact of piped sanitation on birth outcomes differs according to the mothers' socioeconomic characteristics. In particular, the point estimates suggest that the more vulnerable subgroup – that is, younger, single, and less schooled mothers – who are also in a riskier situation of adverse birth

Table 4: Heterogeneous Effects of Sanitation Exposure on Birth Weight

Dependent variable:	Birth Weight					
	Age		Education		Marital Status	
	< 25 y.o.	≥ 25 y.o.	Low	High	Single	Not Single
	(1)	(2)	(3)	(4)	(5)	(6)
Months of Exposure	18.085	26.751***	12.521	19.588***	22.287**	30.490***
	(11.308)	(7.934)	(22.517)	(5.938)	(9.657)	(8.289)
Block Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Month-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Dependent variable mean	3,156.22	3,195.52	3,160.50	3,182.43	3,163.34	3,199.51
Observations	1,633	2,024	744	2,913	2,178	1,479

Notes: This table presents the results of estimating Equation (1) on birth weight for different sub-samples. Columns (1) and (2) present the estimates for mothers up to 24 years old and 25 or more years old, respectively. Columns (3) and (4) show the estimates for mothers with low (up to seven years of formal education) and high (eight or more years of formal education) educational attainment. Columns (5) and (6) present the results for the sub-samples of single and non-single mothers, respectively. All regressions control for: the mother's age, highest schooling level achieved, marital status, the newborn's gender, parity order, and indicators for the hospital of birth. All columns include month-year of conception and block of residence fixed effects. Robust standard errors (in parenthesis) are clustered at the block level. *** Significant at 1%, ** Significant at 5%, * Significant at 10%.

outcomes, is *less* benefited by the policy.

5.3 Additional birth outcomes

In this section, we explore the effects of access to piped sanitation on additional birth outcomes. First, we examine the impact on demand for prenatal appointments as a proxy for maternal behavior change. The literature acknowledges that sanitation can lead to important behavioral changes related to health (Bennett, 2012; Coffey et al., 2018).[21] Recall that the Ministry of Health guideline indicates six prenatal consultations during the pregnancy. Using our data, we can classify mothers as having low prenatal attendance (up to three consultations) or high prenatal attendance (at least seven consultations). Columns (1) and (2) of Table 6 show that overall sanitation has no significant effect on the probability of getting a high or low number of prenatal visits. Both point estimates are negative, but very imprecisely estimated. If anything, we can interpret this result in two ways. Mothers can reduce their defensive behavior as a response to getting access to better sanitation and consequently reduce their demand for prenatal visits. Another explanation is that women seek additional prenatal care

[21] In principle, these changes can be in any direction, as sanitation might improve health behavior (Coffey et al., 2018) or worse it, if it is substitute to another type of infrastructure (Bennett, 2012).

Table 5: Heterogeneous Effects of Sanitation Exposure on the Health Index

Dependent variable:	Health Index					
	Age		Education		Marital Status	
	< 25 y.o.	≥ 25 y.o.	Low	High	Single	Not Single
	(1)	(2)	(3)	(4)	(5)	(6)
Months of Exposure	0.013	0.024**	-0.001	0.017*	0.024*	0.019
	(0.012)	(0.012)	(0.019)	(0.009)	(0.013)	(0.012)
Block Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Month-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Dependent variable mean	-0.01	0.02	-0.01	0.01	-0.01	0.02
Observations	1,633	2,024	744	2,913	2,178	1,479

Notes: This table presents the results of estimating Equation (1) on the health index for different sub-samples. Columns (1) and (2) present the estimates for mothers up to 24 years old and 25 or more years old, respectively. Columns (3) and (4) show the estimates for mothers with low (up to seven years of formal education) and high (eight or more years of formal education) educational attainment. Columns (5) and (6) present the results for the sub-samples of single and non-single mothers, respectively. All regressions control for: the mother's age, highest schooling level achieved, marital status, the newborn's gender, parity order, and indicators for the hospital of birth. All columns include month-year of conception and block of residence fixed effects. Robust standard errors (in parenthesis) are clustered at the block level. *** Significant at 1%, ** Significant at 5%, * Significant at 10%.

when there are any complications during pregnancy, which could have been reduced by exposure to piped sanitation.

The literature also documents that sanitation is correlated with miscarriages and infant mortality (Alsan and Goldin, 2019; Cameron et al., 2021). To investigate these relationships further, we merge birth and mortality records of children up to one year old. Information on miscarriages, however, is not available in the data thus we follow the approach of Koppensteiner and Menezes (2024) and test if piped sanitation affects the sex ratio at birth, which could indicate selection in which fetus survives the intrauterine environment.[22] We display the results of these additional exercises in columns (3) to (6) of Table 6. Column (3) shows a small and statistically insignificant effect of sanitation on the sex ratio at birth. We can interpret this as evidence that sanitation has no selection effect on survival in utero.

Moving to columns (4) to (6), we estimate the effect of exposure to piped sanitation on early neonatal mortality (newborn death in the first week of life), neonatal death (newborn death in the first month of life), and death of the infant up to one year after the birth. Points estimates are positive, but small and statistically insignificant in all cases. Data limitations prevent us from analyzing whether piped sanitation has any effect on fetal deaths.[23]

Table 6: Effects of Sanitation Exposure on Additional Birth Outcomes

Dependent variables:	Prenatal ≥ 7	Prenatal ≤ 3	Female	Early Death (1 week)	Neonatal Death (4 weeks)	Infant Death (1 year)
	(1)	(2)	(3)	(4)	(5)	(6)
Months of Exposure	-0.0033	-0.0007	0.0034	0.0009	0.0006	0.0006
	(0.0050)	(0.0028)	(0.0067)	(0.0009)	(0.0010)	(0.0010)
Block Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Month-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Dependent variable mean	0.73	0.06	0.47	0.00	0.00	0.01
Observations	3,655	3,655	3,657	3,657	3,657	3,657

Notes: This table presents the results of estimating Equation (1) on additional birth outcomes. All regressions control for: the mother's age, highest schooling level achieved, marital status, the newborn's gender, parity order, and indicators for the hospital of birth. All columns include month-year of conception and block of residence fixed effects. Robust standard errors (in parenthesis) are clustered at the block level. *** Significant at 1%, ** Significant at 5%, * Significant at 10%.

5.4 Timing of Effects

It is also relevant to identify critical moments in the pregnancy at which exposure to piped sanitation might have larger effects. We exploit this question by estimating the

[22]The medical and biological literature consider female fetuses more robust to intrauterine shocks; therefore significant effects on the sex ratio may suggest a selection on survival in utero.

[23]Brazilian Ministry of Health defines fetal death as death occurring before the complete extraction of the fetus from the mother, independently of the duration of gestation.

effect of piped sanitation separately by trimester of exposure, following Equation (2). We split the dummy indicating whether the child i was exposed to piped sanitation while in-utero into three distinct dummies, indicating whether the access to sanitation occurred in the first trimester (up to 3 months of pregnancy), the second trimester (between the 4rd and 6th months of pregnancy), or the third trimester (from the 7th month onward). Then, we include the indicators for exposure in the first and second trimesters in our estimating equation and estimate the effects relative to exposure in the third trimester of pregnancy.

Table 7 presents the results of this exercise. Columns (1) and (2) show the coefficients for the regression without and with controls, respectively, on birth weight. We find large and significant positive effects of in-utero exposure to piped sanitation in the first and second trimesters of gestation, in comparison to exposure in the third trimester. The increase in birth weight for those children exposed in the first trimester of pregnancy ranges between 89 and 101 grams, which means an increase in birth weight of roughly 3%. For exposure in the second trimester of pregnancy, the effect is between 56 and 59 grams, which represents an increase of 1.8% in the average birth weight. These results, together with our main result in Table 2, are indicative of a *dosage* effect. That is, children exposed to piped sanitation in earlier stages of pregnancy benefit more than those exposed in later stages of gestation.

In columns (3) and (4) of Table 7, we observe a similar pattern for the health index. The coefficients for exposure in the first and second trimesters are fairly close and large compared to the overall estimate in Table 3, even though they are not significant at the conventional levels. Exposure in the first and second trimesters together accounts for approximately two-thirds of the effect of exposure to piped sanitation during the entire pregnancy ($0.014 \times 9 = 0.126$SD). Thus, we interpret these results as indicative that exposure to piped sanitation at any point within the pregnancy length generates similar cumulative benefits regarding the newborn's overall health.

In Appendix Table A.3, we further examine the effects by trimester on additional birth outcomes. To gain insights into the biological mechanisms that may be driving our results, we check the timing of the impact on the pregnancy length and the fetal growth ratio. Column (1) shows no statistically significant effect of exposure to sanitation works in the first and second trimesters on the pregnancy length in weeks. On the other hand, column (2) indicates that exposure to sanitation in the first trimester of pregnancy increases the fetal growth rate by 2.3 grams per week, for exposure in the second trimester the effect is approximately 1.6 grams per week.

Table 7: Timing of Effects of Sanitation Exposure on Birth Outcomes

Dependent variables:	Birth Weight		Health Index	
	(1)	(2)	(3)	(4)
Sanitation (1st Trimester)	89.342**	101.092***	0.037	0.048
	(38.615)	(38.555)	(0.051)	(0.051)
Sanitation (2nd Trimester)	56.395*	59.808**	0.032	0.036
	(31.425)	(30.096)	(0.037)	(0.036)
Block Fixed Effects	Yes	Yes	Yes	Yes
Month-Year Fixed Effects	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes
Dependent variable mean	3,177.97	3,177.97	0.01	0.01
Observations	3,657	3,657	3,657	3,657

Notes: This table presents the results of estimating Equation (2) on different birth outcomes. The odd-numbered columns present results without controls, while even-numbered columns present the results controlling for: the mother's age, highest schooling level achieved, marital status, the newborn's gender, parity order, and indicators for hospital birth. All columns include month-year of conception and block of residence fixed effects. Robust standard errors (in parenthesis) are clustered at the block level. *** Significant at 1%, ** Significant at 5%, * Significant at 10%.

5.5 Robustness Checks

We perform a battery of robustness checks to assess the validity of our findings. First, a major concern of our empirical analysis regards the possibility of the composition of mothers being related to the months of exposure to the treatment. So far, we have shown that there is little evidence of significant differences in observable characteristics of mothers according to how long they are exposed to piped sanitation within the pregnancy (Table (1)). We only find marginally significant correlations between the treatment and maternal age. This difference is small and unlikely to be driving our results. However, it is still possible that our estimates are biased due to selection in *unobservable* characteristics of the mothers. To address this issue, we follow a large literature and conduct a placebo exercise using siblings' birth outcomes (Currie and Rossin-Slater, 2013; Currie et al., 2022; Da Mata et al., 2023). We match siblings born to the same mother using a probabilistic merge procedure based on maternal time-invariant characteristics, such as name, surname, age and/or date of birth.[24] We maintain the same number of months of exposure for each mother in our original sample and estimate Equation (1) with the birth outcome of siblings born before the arrival of sanitation in the block as the left-hand side variable. We can only find 1,161

[24]Details on the matching procedure are provided in Appendix C.2.

older unexposed siblings to the children in our original sample.

We present the results of this exercise in Table 8. Columns (1) and (2) show that exposure to piped sanitation does not have a statistically significant effect on birth weight and the health index of unexposed older siblings. In columns (3) and (4) we test whether exposure to piped sanitation has any effect on the birth outcomes of the sub-sample of children for which we were able to find older siblings. We find larger and marginally significant point estimates for birth weight (roughly 26.4 grams per additional month of exposure). For the health index, the estimates are not statistically significant, but larger than those obtained for the unexposed older siblings.

Table 8: Effects of Sanitation Exposure on Health Index - Older Siblings

	Unexposed Sibling		Exposed Sibling	
Dependent variables:	Birth Weight	Health Index	Birth Weight	Health Index
	(1)	(2)	(3)	(4)
Months of Exposure	8.267	-0.001	26.398*	0.005
	(7.735)	(0.008)	(15.830)	(0.017)
Block Fixed Effects	Yes	Yes	Yes	Yes
Month-Year Fixed Effects	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Dependent variable mean	3,155.96	0.00	3,216.80	0.03
Observations	1,161	1,161	1,160	1,160

Notes: This table presents the results of estimating Equation (1) on birth outcomes of older unexposed siblings and their siblings in the original sample. Columns (1) and (2) present the results for older unexposed siblings, while columns (3) and (4) display the results for their brothers in the original sample. Controls include: the mother's age, highest schooling level achieved, marital status, the newborn's gender, parity order, and indicators for the hospital of birth. All columns include month-year of conception and block of residence fixed effects. Robust standard errors (in parenthesis) are clustered at the block level. *** Significant at 1%, ** Significant at 5%, * Significant at 10%.

To further lend credibility to our results, we follow Oster (2019)'s method to assess the potential bias due to selection on unobservables. More precisely, we calculate Oster's delta, which indicates how much selection on unobservables relative to observables would be needed to explain away our results.[25] Appendix Table A.4 shows the results of this exercise. Overall, considering the full specification in columns (2) and (4), we observe values of δ between 2.6 and 2.7 (in absolute). These results tell us that selection on unobservables would need to be 2.6 and 2.7 as important as observables to fully explain our results, which is extremely unlikely. By the rule-of-thumb value of 1 (in absolute), proposed by Oster (2019), we can take these results as an indica-

[25] We follow Oster (2019) recommendations and set $\bar{R}_{max}$ to be equal $1.3 \times R^2$, where we obtain R^2 from the regressions with the full set of controls.

tion that our estimates are not driven by omitted variable bias (OVB). Altogether, both previous exercises are compiling evidence that our results are not driven by the unobservable characteristics of the mothers.

Next, recall that in our identification strategy, we explore variation in exposure to piped sanitation during pregnancy across mothers living in the same block. Therefore, the mothers' block of residence and the period of conception are crucial to our research design. Consequently, one might worry that our results are being driven by certain blocks or periods of conception. In Appendix Figure A.2 we assess this possibility and show that this is unlikely to be the case. In panels (a) and (b) we estimate different regressions, dropping observations from each residence in each round. In panels (c) and (d), we repeat the same exercise but exclude each one of the periods of conception instead. In either case, one can note that our results are robust to excluding distinct subsets of our sample. Point estimates remain stable and significant. This exercise shows that our estimates are not driven by any particular block or period.

We also examine how the main results respond when we control for block and neighborhood-specific time trends. These trends account for any varying patterns in unobserved factors across regions. For example, areas with higher geological risks might exhibit distinct trends during periods with increased rainfall, potentially leading to sewage and septic tank overflows. We present the estimates from this exercise in Appendix Table A.5. Columns (1) and (2) show the results for the baseline specification for the birth weight and health index in Panels A and B, respectively. In columns (3) and (4) we include block-specific time trends. The coefficients are higher compared to the baseline specification and remain significant at 1% and 5% levels, respectively. Columns (5) and (6) add neighborhood-specific time trends. Once again, the estimates are higher than in the baseline, and still significant at 1% and 5% levels.[26]

We conduct a placebo exercise by randomly assigning the months of in utero exposure to piped sanitation to the mothers in our sample. We create a random "months of exposure" variable for each mother (0 to 9), with the same distribution as that observed in our sample, and estimate Equation (1) considering this placebo exposure. We repeat this procedure 1,500 times and plot the empirical distribution of the 1,500 placebo effects in Figure A.3. The estimated coefficients for the effect of sanitation facilities on birth weight and the health index lie at the edge of the distribution and are larger by far than most placebo-estimated effects, reassuring that our results do not arise by chance.

Finally, we assess whether our results are robust to alternative clustering schemes. In our preferred specification, we cluster standard errors at the block level. However,

[26] In the regressions including neighborhood-specific linear time trends (columns (5) and (6)), we cluster standard errors at the neighborhood level.

since exposure to piped sanitation in the intrauterine environment depends not only on the blocks of residence of the mothers but also on the date of conception, one might argue that we should also cluster standard errors along this dimension. Column (2) in Panels A and B of Appendix Table A.6 show that our results remain significant using a two-way cluster standard error, along the block and date of conception. There is also room for spatial correlation between the blocks of our analysis since the arrival of piped sanitation might be correlated with common geological and topographical characteristics between neighboring blocks.

5.6 Cost-Benefit Analysis

Our results make it possible to estimate the cost-benefit ratio regarding increased birth weight due to expanding piped sanitation in Campo Grande. The Sanear Morena Program was launched in March 2006, and its cost was disclosed: Sanear 1 invested R$198 million and made 55,750 residential connections; Sanear 2 invested R$57 million and made 13,000 residential connections; and Sanear 3 must invest R$636 million to connect 126,000 homes. Bringing these values to December 2022 and considering the average cost of the residential connection, we have a value of US$2,070 (exchange rate of R$5.2/US$). In addition, the cost of connecting the sewage is US$191, which can be paid in 36 installments on the monthly water and sewage bill, totaling US$2,262 per home.

On the benefit side, we use the estimates provided by Behrman and Rosenzweig (2004) and Clarke et al. (2021) for the USA to determine the present value of an additional gram of birth weight. Clarke et al. (2021) employed the estimate provided by Behrman and Rosenzweig (2004) that each pound of increase in birth weight results in a 7% increase in an adult's earnings. According to Clarke et al. (2021), the present value of each additional gram of weight is US$14. The 178-gram gain – when pregnant women are fully exposed to sanitation - generates a total gain of US$2,501 per child. This value implies a net gain of approximately US$239 (or R$ 1,243).[27]

Although informative, these back-of-the-envelope calculations likely underestimate the benefits, as it does not take into consideration well-established benefits on other future outcomes, such as health, which would generate a reduction in expenses related to hospitalizations. On the top of that, even benefits related to labor market returns are arguably underestimated, since returns to birth weight in low- and middle-income countries are likely to be larger than in developed countries (Currie and Vogl, 2013;

[27] This exercise requires the choice of a reference point of exposure to calculate its effects on birth weight. In the main calculations, we take as reference exposure throughout the entire pregnancy to estimate the *maximum* benefit of in-utero exposure to improved sanitation. If instead we use the average length of exposure in our sample (4.70 months), we find a benefit of US$1,306 per child.

Da Mata et al., 2023). Hence, our results indicate that expanding access to improved sanitation is a cost-effective way of improving individuals' health.

6 Concluding Remarks

This paper examines the effects of access to improved sanitation on infant health. To do that, we explore the large expansion in access to piped sanitation in Campo Grande, a large Brazilian capital. Combining individual-level administrative datasets on birth records and geocoded data on the provision of sanitation infrastructure, we compare children born to mothers exposed to similar infrastructure, other than sanitation, during their pregnancies. We add to the well-established literature on the effects of prenatal shocks on infant health. In particular, we shed light on the impacts of an expansion in sanitation infrastructure on birth outcomes, a surprisingly understudied question (Cameron et al., 2021).

Our results indicate that exposure to improved sanitation *in utero* causes a large increase in birth weight and an improvement in the newborn's overall health. The positive effect on birth weight is large compared to almost any other *in utero* shock discussed in the literature and only matched in magnitude to the negative effects of exposure to pollution documented by Mouganie et al. (2023). We investigate two possible biological channels to these effects: (i) increases in the duration of the gestation, and (ii) reduction of fetal growth restriction. Our findings suggest that the second biological channel (i.e. reduction in fetal growth restrictions) drives our results, consistent with what is proposed in the biological literature (Kramer, 1987a).

Further analysis reveals that the average effect can mask substantial heterogeneity. Our results on this front suggest that the most vulnerable group (composed of younger, less educated, and single mothers) might benefit *less* from the expansion of sanitation infrastructure. We interpret this finding in light of the "last-mile problem", which in our context would mean that more vulnerable mothers have more difficulty accessing sanitation. One possible explanation is that more vulnerable mothers are unable to pay for the installation and maintenance of improved sanitation services. Our results highlight that policymakers may need to consider that these heterogeneous effects can reduce the benefits of improvement in sanitation to the more deprived strata of the population, then complementary policies might be needed to scale the impact of the infrastructure intervention.

Overall, this study enhances our understanding of the possible effects of piped sanitation on newborn's health, an important outcome with long-lasting effects on individuals' lives. Therefore, an avenue for future research is to investigate how exposure to improved sanitation in utero may affect health at other stages of life, human capital accumulation, and income.

Bibliography

AbconSindcon, "Panorama da participação privada no saneamento 2023," 2023.

Adegnika, Ayola A, Selidji T Agnandji, Sanders K Chai, Michael Ramharter, Lutz Breitling, Eric Kendjo, Saadou Issifou, Maria Yazdanbakhsh, Maryvonne Kombila, and Peter G Kremsner, "Increased prevalence of intestinal helminth infection during pregnancy in a Sub-Saharan African community," *Wiener Klinische Wochenschrift*, 2007, *119* (23), 712–716.

Almond, Douglas and Janet Currie, "Killing me softly: The fetal origins hypothesis," *Journal of economic perspectives*, 2011, *25* (3), 153–172.

_ , Hilary W Hoynes, and Diane Whitmore Schanzenbach, "Inside the war on poverty: The impact of food stamps on birth outcomes," *The review of economics and statistics*, 2011, *93* (2), 387–403.

_ , Janet Currie, and Valentina Duque, "Childhood circumstances and adult outcomes: Act II," *Journal of Economic Literature*, 2018, *56* (4), 1360–1446.

_ , Kenneth Y Chay, and David S Lee, "The costs of low birth weight," *The Quarterly Journal of Economics*, 2005, *120* (3), 1031–1083.

Alsan, Marcella and Claudia Goldin, "Watersheds in child mortality: The role of effective water and sewerage infrastructure, 1880–1920," *Journal of Political Economy*, 2019, *127* (2), 586–638.

Amarante, Verónica, Marco Manacorda, Edward Miguel, and Andrea Vigorito, "Do cash transfers improve birth outcomes? Evidence from matched vital statistics, and program and social security data," *American Economic Journal: Economic Policy*, 2016, *8* (2), 1–43.

Anderson, Michael L, "Multiple inference and gender differences in the effects of early intervention: A reevaluation of the Abecedarian, Perry Preschool, and Early Training Projects," *Journal of the American statistical Association*, 2008, *103* (484), 1481–1495.

Ashraf, Nava, Edward L Glaeser, and Giacomo AM Ponzetto, "Infrastructure, incentives, and institutions," *American Economic Review*, 2016, *106* (5), 77–82.

Bancalari, Antonella, "The unintended consequences of infrastructure development," *Review of Economics and Statistics*, 2024, pp. 1–44.

Barreto, Mauricio L, Bernd Genser, Agostino Strina, Ana Marlucia O Assis, Rita F Rego, Carlos A Teles, Matildes S Prado, Sheila MA Matos, Darci N Santos, Lenaldo A dos Santos et al., "Effect of city-wide sanitation programme on reduction in rate of childhood diarrhoea in northeast Brazil: assessment by two cohort studies," *The Lancet*, 2007, *370* (9599), 1622–1628.

Behrman, Jere R and Mark R Rosenzweig, "Returns to birthweight," *Review of Economics and statistics*, 2004, *86* (2), 586–601.

Bennett, Daniel, "Does Clean Water Make You Dirty?: Water Supply and Sanitation in the Philippines," *Journal of Human Resources*, 2012, *47* (1), 146–173.

Bhalotra, Sonia R, Alberto Diaz-Cayeros, Grant Miller, Alfonso Miranda, and Atheendar S Venkataramani, "Urban water disinfection and mortality decline in lower-income countries," *American Economic Journal: Economic Policy*, 2021, *13* (4), 490–520.

Bharadwaj, Prashant, Petter Lundborg, and Dan-Olof Rooth, "Birth weight in the long run," *Journal of Human Resources*, 2018, *53* (1), 189–231.

Black, Sandra E, Paul J Devereux, and Kjell G Salvanes, "From the cradle to the labor market? The effect of birth weight on adult outcomes," *The Quarterly Journal of Economics*, 2007, *122* (1), 409–439.

_ , _ , and _ , "Does grief transfer across generations? Bereavements during pregnancy and child outcomes," *American Economic Journal: Applied Economics*, 2016, *8* (1), 193–223.

BRASIL, TRATA, "Ociosidade das Redes de Esgotamento Sanitário no Brasil. 2015," 2018.

Brooker, Simon, Peter J Hotez, and Donald AP Bundy, "Hookworm-related anaemia among pregnant women: a systematic review," *PLoS neglected tropical diseases*, 2008, *2* (9), e291.

Buchala, Aregahegn Dona, Siyoum Tesfaw Mengistu, Azmach Dache Mue, and Amelo Bolka Gujo, "Prevalence of intestinal parasitic infections and associated factors among pregnant women attending antenatal care at Yirgalem General Hospital, Sidama, Ethiopia," *Clinical Epidemiology and Global Health*, 2022, *15*, 101032.

Cameron, Lisa, Claire Chase, and Diana Contreras Suarez, "Relationship between water and sanitation and maternal health: evidence from Indonesia," *World Development*, 2021, *147*, 105637.

Clarke, Damian, Sonia Oreffice, and Climent Quintana-Domeque, "On the value of birth weight," *Oxford Bulletin of Economics and Statistics*, 2021, *83* (5), 1130–1159.

Coffey, Diane, Michael Geruso, and Dean Spears, "Sanitation, disease externalities and anaemia: evidence from Nepal," *The Economic Journal*, 2018, *128* (611), 1395–1432.

Conley, Timothy G, "GMM estimation with cross sectional dependence," *Journal of econometrics*, 1999, *92* (1), 1–45.

Currie, Janet and Maya Rossin-Slater, "Weathering the storm: Hurricanes and birth outcomes," *Journal of health economics*, 2013, *32* (3), 487–503.

_ **and Tom Vogl**, "Early-life health and adult circumstance in developing countries," *Annu. Rev. Econ.*, 2013, *5* (1), 1–36.

_ **, Michael Mueller-Smith, and Maya Rossin-Slater**, "Violence while in utero: The impact of assaults during pregnancy on birth outcomes," *The Review of Economics and Statistics*, 2022, *104* (3), 525–540.

de Lemos Capanema, Luciana Xavier, "Implementação do novo marco legal do saneamento: a importância da regulação por contrato em um cenário atual de transição regulatória," *https://web. bndes. gov. br/bib/jspui/handle/1408/22564*, 2022.

_ , "Reflexões sobre o desafio da universalização do saneamento a partir da implementação do novo marco legal," 2022.

de Oliveira, Fernanda Almeida Fernandes, Irene Guimarães Altafin, Rafael Martins de Souza, and Raquel Maria Soares Freitas, "Efetividade dos investimentos em saneamento no Brasil: da disponibilidade dos recursos financeiros à implantação dos sistemas de abastecimento de água e de esgotamento sanitário," 2016.

Delmon, Jeff, "Understanding Options for Public-Private Partnerships in Infrastructure: Sorting Out the Forest from the Trees: Bot, Dbfo, Dcmf, Concession, Lease..," *World Bank policy research working paper*, 2010, (5173).

Deutschmann, Joshua W, Molly Lipscomb, Laura Schechter, and Jessica Zhu, *Spillovers without social interactions in urban sanitation*, BREAD, the Bureau for Research and Economic Analysis of Development, 2021.

Devoto, Florencia, Esther Duflo, Pascaline Dupas, William Parienté, and Vincent Pons, "Happiness on tap: Piped water adoption in urban Morocco," *American Economic Journal: Economic Policy*, 2012, *4* (4), 68–99.

dos Anjos, Juliana Cristine and Antonio Fernando Boing, "Diferenças regionais e fatores associados ao número de consultas de pré-natal no Brasil: análise do Sistema de Informações sobre Nascidos Vivos em 2013," *Revista Brasileira de Epidemiologia*, 2016, *19*, 835–850.

Figlio, David, Jonathan Guryan, Krzysztof Karbownik, and Jeffrey Roth, "The effects of poor neonatal health on children's cognitive development," *American Economic Review*, 2014, *104* (12), 3921–3955.

Fraser, Alison M, John E Brockert, and Ryk H Ward, "Association of young maternal age with adverse reproductive outcomes," *New England journal of medicine*, 1995, *332* (17), 1113–1118.

Galiani, Sebastian, Paul Gertler, and Ernesto Schargrodsky, "Water for life: The impact of the privatization of water services on child mortality," *Journal of political economy*, 2005, *113* (1), 83–120.

Gertler, Paul and Susumu Yoshida, "ENFORCING PAYMENT FOR WATER AND SANITATION SERVICES IN NAIROBI'S SLUMS Aidan Coville Sebastian Galiani," 2020.

Gertler, Paul J, Sebastian Martinez, Patrick Premand, Laura B Rawlings, and Christel MJ Vermeersch, *Impact evaluation in practice*, World Bank Publications, 2016.

Geruso, Michael and Dean Spears, "Neighborhood sanitation and infant mortality," *American Economic Journal: Applied Economics*, 2018, *10* (2), 125–162.

Getachew, Million, Delenesaw Yewhalaw, Ketema Tafess, Yehenew Getachew, and Ahmed Zeynudin, "Anaemia and associated risk factors among pregnant women in Gilgel Gibe dam area, Southwest Ethiopia," *Parasites & vectors*, 2012, *5* (1), 1–8.

González, Libertad and Sofia Trommlerová, "Cash transfers before pregnancy and infant health," *Journal of Health Economics*, 2022, *83*, 102622.

Goswami, Toral M, VN Patel, NH Pandya, AK Mevada, KS Desai, Kalpesh B Solanki et al., "Maternal anaemia during pregnancy and its impact on perinatal outcome," *Int J Biomed Adv Res*, 2014, *5* (02), 99–102.

Hoynes, Hilary, Marianne Page, and Ann Huff Stevens, "Can targeted transfers improve birth outcomes?: Evidence from the introduction of the WIC program," *Journal of Public Economics*, 2011, *95* (7-8), 813–827.

Imas, Linda G Morra and Ray Rist, *The road to results: Designing and conducting effective development evaluations* 2009.

Kesztenbaum, Lionel and Jean-Laurent Rosenthal, "Sewers' diffusion and the decline of mortality: The case of Paris, 1880–1914," *Journal of Urban Economics*, 2017, *98*, 174–186.

Koppensteiner, Martin Foureaux and Lívia Menezes, "Maternal dengue and health outcomes of children," *American Economic Journal: Applied Economics*, 2024, *16* (2), 530–553.

_ **and Marco Manacorda**, "Violence and birth outcomes: Evidence from homicides in Brazil," *Journal of Development Economics*, 2016, *119*, 16–33.

Kramer, Michael S, "Determinants of low birth weight: methodological assessment and meta-analysis.," *Bulletin of the world health organization*, 1987, *65* (5), 663.

_ , "Intrauterine growth and gestational duration determinants," *Pediatrics*, 1987, *80* (4), 502–511.

Kresch, Evan Plous, "The buck stops where? federalism, uncertainty, and investment in the brazilian water and sanitation sector," *American Economic Journal: Economic Policy*, 2020, *12* (3), 374–401.

— , **Mark Walker, Michael Carlos Best, François Gerard, and Joana Naritomi**, "Sanitation and property tax compliance: Analyzing the social contract in Brazil," *Journal of Development Economics*, 2023, *160*, 102954.

— , **Molly Lipscomb, and Laura Schechter**, "Externalities and spillovers from sanitation and waste management in urban and rural neighborhoods," *Applied Economic Perspectives and Policy*, 2020, *42* (3), 395–420.

Lovisa, Hevelin, Juliana Spezia, and Mauren Isfer Anghebem-Oliveira, "HELMINTH INFECTIONS IN PREGNANCY: FROM MATERNAL-FETAL COMMITMENT TO TREATMENT," *Visão Acadêmica*, 2016, *17* (1).

Mahmood, Lubna, "The metabolic processes of folic acid and Vitamin B12 deficiency," *Journal of Health Research and Reviews (In Developing Countries)*, 2014, *1* (1), 5–9.

Marcus, Michelle, "Going beneath the surface: Petroleum pollution, regulation, and health," *American Economic Journal: Applied Economics*, 2021, *13* (1), 72–104.

Mata, Daniel Da and Pedro Drugowick, "The consequences of health mandates on infant health: Evidence from a smoking-ban regulation," *Journal of Development Economics*, 2024, *167*, 103171.

— , **Lucas Emanuel, Vitor Pereira, and Breno Sampaio**, "Climate adaptation policies and infant health: evidence from a water policy in Brazil," *Journal of Public Economics*, 2023, *220*, 104835.

Mehra, Rekha, "Targeting Poverty and Gender Inequality to Improve Maternal Health," 2010.

Mouganie, Pierre, Ruba Ajeeb, and Mark Hoekstra, "The effect of open-air waste burning on infant health: evidence from government failure in Lebanon," *Journal of Human Resources*, 2023.

Oster, Emily, "Unobservable selection and coefficient stability: Theory and evidence," *Journal of Business & Economic Statistics*, 2019, *37* (2), 187–204.

Padhi, Bijaya K, Kelly K Baker, Ambarish Dutta, Oliver Cumming, Matthew C Freeman, Radhanatha Satpathy, Bhabani S Das, and Pinaki Panigrahi, "Risk of adverse pregnancy outcomes among women practicing poor sanitation in rural India: a population-based prospective cohort study," *PLoS medicine*, 2015, *12* (7), e1001851.

Patel, Ratna, Ajay Gupta, Shekhar Chauhan, and Dhananjay W Bansod, "Effects of sanitation practices on adverse pregnancy outcomes in India: a conducive finding from recent Indian demographic health survey," *BMC pregnancy and childbirth*, 2019, *19*, 1–12.

Pereira, Reobbe Aguiar, João Noronha Teles, and Cristina Maciel Lima Costa, "A importância do ácido fólico e sulfato ferroso na gestação," *Revista Extensão*, 2019, *3* (1), 75–82.

Prefeitura Municipal de Campo Grande, "Decreto nº 12.254, de 26 de dezembro de 2013," *Diário Oficial de Campo Grande*, 2013.

Rosito, Carlos Alberto, "Do Planasa ao Plansab: os últimos 50 anos da água e do esgoto no Brasil," *SAINT-GOBAIN CANALIZAÇÃO*, 2019.

Schirmer, J et al., "Assistência pré-natal: manual técnico," *Brasília: Secretaria de Políticas de Saúde, Ministério da Saúde*, 2000.

Schlaudecker, Elizabeth P, Flor M Munoz, Azucena Bardají, Nansi S Boghossian, Asma Khalil, Hatem Mousa, Mirjana Nesin, Muhammad Imran Nisar, Vitali Pool, Hans ML Spiegel et al., "Small for gestational age: Case definition & guidelines for data collection, analysis, and presentation of maternal immunisation safety data," *Vaccine*, 2017, *35* (48Part A), 6518.

Shah, Manisha and Bryce Millett Steinberg, "Drought of opportunities: Contemporaneous and long-term impacts of rainfall shocks on human capital," *Journal of Political Economy*, 2017, *125* (2), 527–561.

Shah, Prakesh S, Jamie Zao, and Samana Ali, "Maternal marital status and birth outcomes: a systematic review and meta-analyses," *Maternal and child health journal*, 2011, *15*, 1097–1109.

SNIS, "Diagnóstico Temático Serviços de Água e Esgoto," 2020.

_ , "Diagnóstico Temático Serviços de Água e Esgoto," 2023.

Stepping, Katharina, *Urban sewage in Brazil: drivers of and obstacles to wastewater treatment and reuse. Governing the Water-Energy-Food Nexus Series* number 26/2016, Discussion Paper, 2016.

Thame, Gizele, Elvira Maria Guerra Shinohara, Hosana Gonçalves dos Santos, and Antonio Fernandes Moron, "Folato, vitamina B12 e ferritina sérica e defeitos do tubo neural," *Revista Brasileira de Ginecologia e Obstetrícia*, 1998, *20*, 449–453.

Theme-Filha, Mariza Miranda, Marcia Leonardi Baldisserotto, Ana Claudia Santos Amaral Fraga, Susan Ayers, Silvana Granado Nogueira da Gama, and Maria do Carmo Leal, "Factors associated with unintended pregnancy in Brazil: cross-sectional results from the Birth in Brazil National Survey, 2011/2012," *Reproductive health*, 2016, *13*, 235–243.

Tsoka-Gwegweni, Joyce Mahlako and NP Ntombela, "A double load to carry: parasites and pregnancy," *Southern African Journal of Infectious Diseases*, 2014, *29* (2), 52–55.

Viellas, Elaine Fernandes, Rosa Maria Soares Madeira Domingues, Marcos Augusto Bastos Dias, Silvana Granado Nogueira da Gama, Mariza Miranda Theme Filha, Janaina Viana da Costa, Maria Helena Bastos, and Maria do Carmo Leal, "Assistência pré-natal no Brasil Prenatal care in Brazil El cuidado prenatal en Brasil," *Cad Saude Publica*, 2014, *30*, 85–100.

Wekesa, AW, CS Mulambalah, CI Muleke, R Odhiambo et al., "Intestinal helminth infections in pregnant women attending antenatal clinic at Kitale district hospital, Kenya," *Journal of parasitology research*, 2014, *2014.*

WHO, "Progress on household drinking-water, sanitation and hygiene 2000-2022: Special focus on gender," 2023.

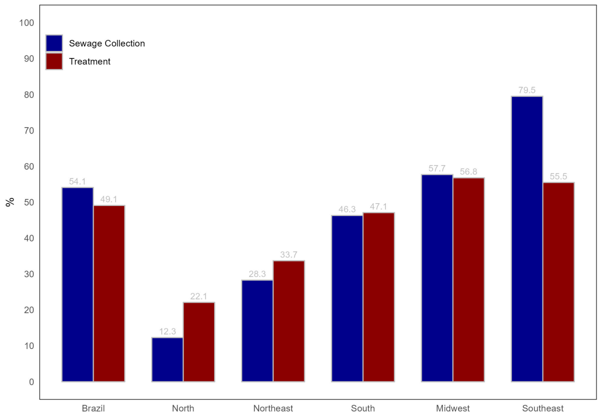
Online Appendix to "The Effects of Sanitation on Infant Health: Evidence from Brazil"

Fernanda Batolla, Daniel Da Mata and Pedro Oliveira

July 22, 2024

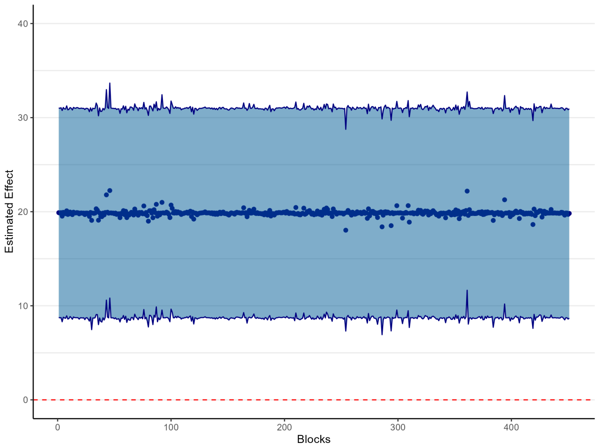
A Extra Tables and Figures

Figure A.1: Brazil Service Level by Regions (2019)

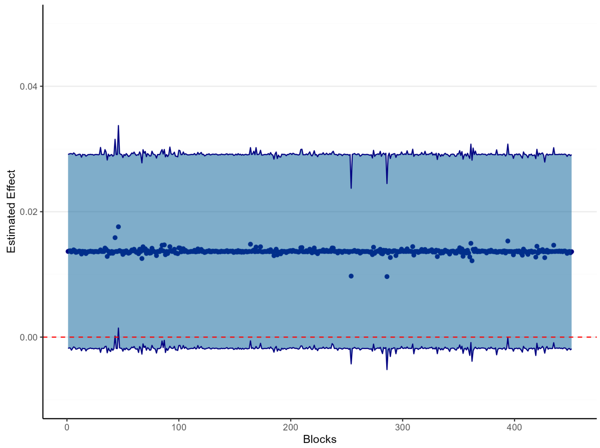


Notes: The figure shows the percentage of the population served with piped sanitation and sewage treatment. Source: SNIS (2020). We considered the index of service for the total population with sewage collection (IN056) and the index of treatment of generated sewage (IN046).

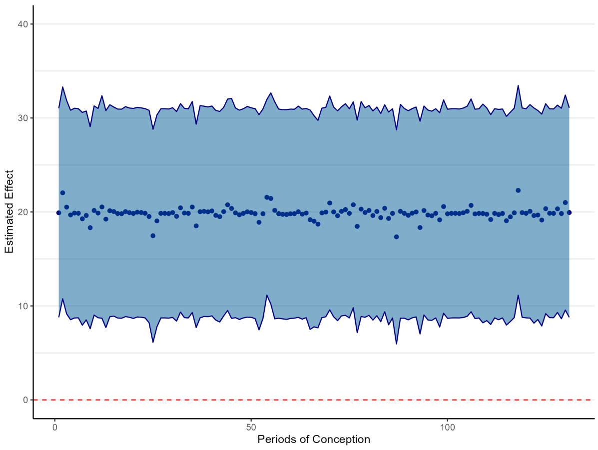
Figure A.2: Robustness to dropping Blocks and Periods of Conception



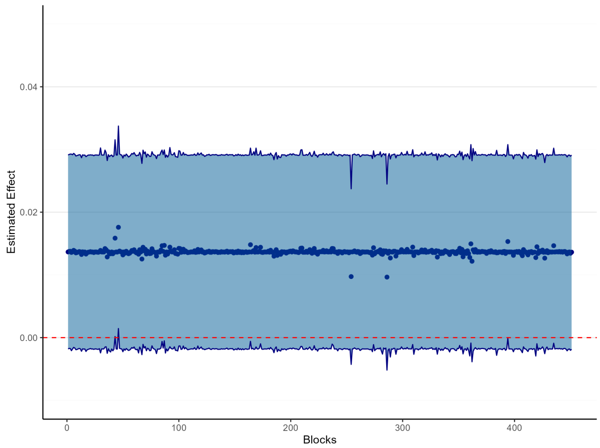
(a) Dropping Blocks - Birth Weight



(b) Dropping Blocks - Health Index



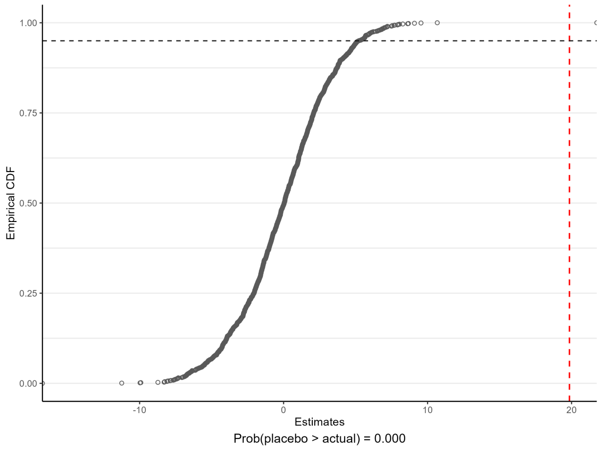
(c) Dropping Periods of Conception - Birth Weight



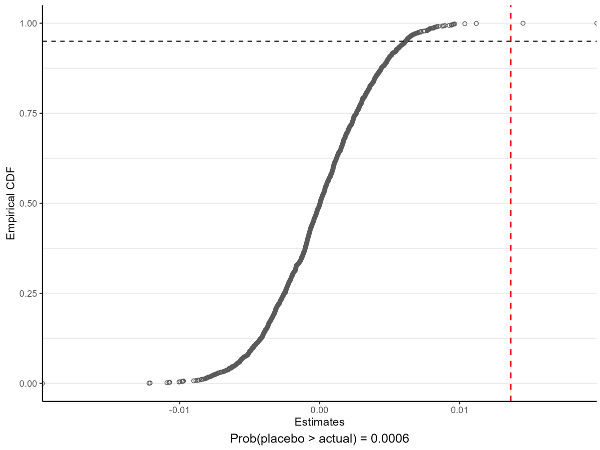
(d) Dropping Periods of Conception - Health Index

Notes: Panels (a) and (b) show the results of multiple regressions for birth weight and the health index, respectively, dropping observations from one residence block at a time. Panels (c) and (d) repeat the same exercise dropping periods of conception instead. All regressions follow the specification in Equation (1). Robust standard errors are clustered at the block level.

Figure A.3: Placebo Effects of Sanitation on Birth Outcomes



(a) Birth Weight



(b) Health Index

Notes: Panels (a) and (b) show the results of 1,500 placebo treatments for birth weight and the health index, respectively. The red dashed line represents the *actual* coefficients, reported in Tables 2 and 3. All regressions follow the specification of Equation (1). Standard errors are clustered at the block level.

Table A.1: Capital's Sewage Collection

Year	2005	2019	2005-19 p.p.
North			
Boa Vista	19.8	87.9	68.1
Palmas	34.3	85.7	51.4
Rio Branco	19.2	21.7	2.5
Manaus	11.2	19.9	8.7
Belém	6.7	15.8	9.1
Macapá	7.1	11.0	3.9
Porto Velho	2.2	4.7	2.5
Northeast			
João Pessoa	50.6	80.6	30.0
Salvador	68.7	79.3	10.6
Aracaju	30.3	55.2	24.9
Fortaleza	54.1	50.0	-4.2
São Luís	48.5	49.7	1.1
Recife	44.0	44.0	0.0
Maceió	28.1	43.0	15.0
Natal	32.7	42.7	9.9
Teresina	16.0	34.0	18.0
Midwest			
Goiânia	73.9	92.7	18.8
Brasília	92.7	89.5	-3.2
Campo Grande	22.2	82.9	60.7
Cuiabá	36.6	61.6	25.0
Southeast			
São Paulo	86.4	96.3	9.9
Belo Horizonte	93.6	93.9	0.3
Rio de Janeiro	82.9	86.3	3.4
Vitória	53.5	81.3	27.8
South			
Curitiba	78.0	100.0	22.0
Porto Alegre	85.5	91.3	5.8
Florianópolis	44.2	64.8	20.6

Notes: Source: SNIS-Historical Series, data aggregated by municipalities. We use the index of service for the total population with sewage collection (IN056).

Table A.2: Effects of Sanitation Exposure on the Birth Weight Distribution

Dependent Variables:	BW < 1500 (1)	BW < 1600 (2)	BW < 1700 (3)	BW < 1800 (4)	BW < 1900 (5)	BW < 2000 (6)	BW < 2100 (7)
Months of Exposure	-0.001	-0.001	-0.002	-0.002	-0.002	-0.004*	-0.005**
	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Dependent variable mean	0.01	0.01	0.02	0.02	0.02	0.02	0.03
	BW < 2200 (8)	BW < 2300 (9)	BW < 2400 (10)	BW < 2500 (11)	BW < 2600 (12)	BW < 2700 (13)	BW < 2800 (14)
	-0.004	-0.004	-0.004	-0.004	-0.003	-0.005	-0.004
	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)
Dependent variable mean	0.04	0.05	0.06	0.07	0.09	0.13	0.17
Dependent Variables:	BW < 2900 (15)	BW < 3000 (16)	BW < 3100 (17)	BW < 3200 (18)	BW < 3300 (19)	BW < 3400 (20)	BW < 3500 (21)
Months of Exposure	-0.010**	-0.015***	-0.016***	-0.016***	-0.016***	-0.014***	-0.013***
	(0.005)	(0.005)	(0.006)	(0.006)	(0.005)	(0.005)	(0.005)
Dependent variable mean	0.24	0.31	0.40	0.50	0.59	0.68	0.76
Conception Year and Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Block FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Block Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3,657	3,657	3,657	3,657	3,657	3,657	3,657

Notes: This table presents the results of estimating Equation (1) on the probability of being below multiple thresholds of birth weight. All columns controls for: the mother's age, highest schooling level achieved, marital status, the newborn's gender, parity order, and indicators for the hospital of birth. All columns include month-year of conception and block of residence fixed effects. Robust standard errors (in parenthesis) are clustered at the block level. *** Significant at 1%, ** Significant at 5%, * Significant at 10%.

Table A.3: Timing of Effects of Sanitation Exposure on Additional Birth Outcomes

Dependent variables:	Weeks of Gestation	Fetal Growth Rate
	(1)	(2)
Sanitation (1st Trimester)	0.213	2.302**
	(0.146)	(0.911)
Sanitation (2nd Trimester)	0.066	1.592**
	(0.124)	(0.719)
Block Fixed Effects	Yes	Yes
Month-Year Fixed Effects	Yes	Yes
Controls	Yes	Yes
Dependent variable mean	38.50	82.37
Observations	3,657	3,657

Notes: This table presents the results of estimating Equation (2) on different birth outcomes. All regressions control for: the mother's age, highest schooling level achieved, marital status, the newborn's gender, parity order, and indicators for hospital birth. All columns include month-year of conception and block of residence fixed effects. Robust standard errors (in parenthesis) are clustered at the block level. *** Significant at 1%, ** Significant at 5%, * Significant at 10%.

Table A.4: Effects of Sanitation Exposure on Health Index - Oster Robustness

Dependent variables:	Birth Weight		Health Index	
	(1)	(2)	(3)	(4)
Months of Exposure	18.402***	19.853***	0.012	0.014*
	(5.675)	(5.680)	(0.008)	(0.008)
Block Fixed Effects	Yes	Yes	Yes	Yes
Month-Year Fixed Effects	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes
Dependent variable mean	3,177.97	3,177.97	0.01	0.01
Null Effect Selection Ration (δ)	-2.570	-2.604	-2.666	-2.712
Observations	3,657	3,657	3,657	3,657

Notes: This table presents the results of estimating Equation (1) on birth outcomes. Columns (1) and (2) show the results for birth weight. Columns (3) and (4) show the results for the health index. The odd-numbered columns present results without controls, while even-numbered columns present the results controlling for: the mother's age, highest schooling level achieved, marital status, the newborn's gender, parity order, and indicators for the hospital of birth. All columns include month-year of conception and block of residence fixed effects. Robust standard errors (in parenthesis) are clustered at the block level. *** Significant at 1%, ** Significant at 5%, * Significant at 10%.

Table A.5: Effects of Sanitation Exposure on Birth Outcomes - Sensitivity Analysis

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Birth Weight						
Months of Exposure	18.402***	19.853***	26.179***	28.495***	23.781***	25.654***
	(5.675)	(5.680)	(8.098)	(8.077)	(6.062)	(5.887)
Panel B: Health Index						
Months of Exposure	0.012	0.014*	0.023**	0.026**	0.016*	0.018**
	(0.008)	(0.008)	(0.011)	(0.011)	(0.008)	(0.008)
Block Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Month-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes	No	Yes
Block Linear Trends	No	No	Yes	Yes	No	No
Neighborhood Linear Trends	No	No	No	No	Yes	Yes
Dependent variable mean	3,177.97	3,177.97	3,177.97	3,177.97	3,177.97	3,177.97
Observations	3,657	3,657	3,657	3,657	3,657	3,657

Notes: This table presents the results of estimating Equation (1) on birth outcomes. Panel A presents the results for the birth weight. Panel B presents the results for the health index. Columns (1) and (2) show the baseline results without and with control, respectively. Columns (3) and (4) show the results analogous to columns (1) and (2), including block-specific linear trends. Columns (5) and (6) show the results analogous to columns (1) and (2), including neighborhood-specific linear trends. The odd-numbered columns present results without controls, while even-numbered columns present the results controlling for: the mother's age, highest schooling level achieved, marital status, the newborn's gender, parity order, and indicators for the hospital of birth. All columns include month-year of conception and block of residence fixed effects. Robust standard errors (in parenthesis) are clustered at the block level. *** Significant at 1%, ** Significant at 5%, * Significant at 10%.

Table A.6: Effects of Sanitation Exposure on Birth Outcomes - Alternative Clustering

			Conley spatial clustering				
	Baseline	Block + Period	3km	6km	9km	12km	15km
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: Birth Weight							
Months of Exposure	19.853***	19.853***	19.853*	19.853	19.853**	19.853**	19.853***
	(5.680)	(5.606)	(11.484)	(12.898)	(10.095)	(9.414)	(6.156)
Panel B: Health Index							
Months of Exposure	0.014*	0.014	0.014	0.014	0.014	0.014*	0.014**
	(0.008)	(0.009)	(0.012)	(0.016)	(0.010)	(0.008)	(0.006)
Block Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3,657	3,657	3,657	3,657	3,657	3,657	3,657

Notes: This table presents the results of estimating Equation (1) on birth outcomes. Panel A presents the results for the birth weight. Panel B presents the results for the health index. Column (1) shows our baseline estimates, with standard errors clustered at the block level. Column (2) reports two-way clustered standard errors, at the block-period of conception level. Columns (3) to (7) report the results using Conley (1999) standard errors, accounting for spatial correlation, with distance cutoff varying from 3 to 15 kilometers. Controls include the mother's age, highest schooling level achieved, marital status, the newborn's gender, parity order, and indicator for hospital birth. All columns include month-year of conception and block of residence fixed effects. Robust standard errors (in parenthesis) are clustered at the block level. *** Significant at 1%, ** Significant at 5%, * Significant at 10%.

B Sanitation Sector in Brazil

B.1 Evolution of the Sanitation Regulatory Framework

In 1970 Brazil, only 50% of the urban population had treated water, and 19% had piped sanitation. In 1971, the military government implemented the National Basic Sanitation Plan (Planasa), which created and financially strengthened the State Basic Sanitation Companies (CESBs). With Planasa, it is the first time that the federal government has implemented a national sanitation policy, carried out by the National Housing Bank (BNH), and with a large amount of resources available for investment, coming from the service time guarantee fund. Planasa aimed to reach at least 80% of the urban population with treated water and 50% with piped sanitation by 1980 (Rosito, 2019).

Thus, despite the municipality owning the service, CESBs began operating water and sewage services in most cities through program contracts for 20-25 years. Municipalities were strongly encouraged to grant services to CESBs. Otherwise, they would not receive Planasa resources. The Planasa led to the regionalization of service provision since CESBs operated interconnected systems (within their respective state) and adopted cross-subsidization (cities with surplus systems financed cities with deficit systems) (Capanema, 2022b).

In the 1980s and 1990s, state public services lost their financing capacity due to the economic crisis and high inflation. The BNH, burdened with debt, was extinguished in 1986. Caixa Economica Federal took over the BNH's assets, not the sanitation sector's regulatory function. Planasa was finished in 1990, leaving an institutional void in the segment (Stepping, 2016).

The country's re-democratization and the Federal Constitution 1988 decentralized sectoral policies and strengthened municipalities. In the 1990s, the role of State changed from direct intervener to regulator. Some infrastructure sectors, such as electricity and telecommunications, were privatized and developed, with universal services in 2011 and 2012, respectively (Capanema, 2022a).

However, this did not happen with the sanitation sector, which experienced a period of oblivion in the public policy agenda, marked by institutional limbo and low investment (Oliveira et al., 2016). The Concessions Law (Law 8,987/1995), which allowed private participation in the provision of public services, and the PPP Law (Law 11,079/2004), which established the rules for contracting public-private partnerships within the scope of public administration, had minimal effect on the sanitation sector, due, among other factors, to the regulatory fragility of the industry (Oliveira et al., 2016; Capanema, 2022b).

In this sense, the National Basic Sanitation Law (Law 11,445/2007) began redesigning the institutional and regulatory framework. The big news was the obligation for municipalities to draw up a Municipal Basic Sanitation Plan (PMSB) with clear service targets for the population (Oliveira et al., 2016). Also, in 2007, the federal government launched the Growth Acceleration Program (PAC) to promote economic growth by investing in infrastructure sectors. Among the PAC's actions, the sanitation sector received strong financial stimulus, which increased the volume of investments from 2007 to 2014.

The National Basic Sanitation Plan, provided for in the Sanitation Law and approved in 2013, established goals to achieve service universalization within 20 years. This means that, in 2033, 99% of the population will have access to treated water and 90% to piped sanitation. The Plan promoted a broad debate between the federal government, federative entities, and society.

Despite these advances, legal uncertainties still disfavored private investment in the sanitation sector. The two main problems were: i) the existence of program contracts (with CESBs or local authorities), which allowed contracts to be renewed with city hall without bidding, and ii) extremely dispersed regulation since the legislation allows for municipal, regional, and state regulatory agencies (Oliveira et al., 2016; Capanema, 2022b). In 2020, there were 86 regulatory agencies in Brazil, which increased costs for sanitation companies that operate in more than one city and need to adapt to different rules when providing the same service. Furthermore, these agencies are characterized by low technical quality (Capanema, 2022b).

The New Framework for Basic Sanitation (Law 14,026/2020) aimed to standardize the rules, increase legal security, and attract private investments to the sector (Capanema, 2022a). The main changes were the renewal of the contract only through bidding (extinction of the program contract) and the strengthening of the National Water and Sanitation Agency (ANA) as a federal regulatory agency responsible for standardizing the rules of subnational regulatory agencies (Capanema, 2022b).

Finally, Law 14,026 also introduced a new regionalization model: bidding for services must be done in blocks (larger municipalities finance smaller ones) to guarantee universalization for all municipalities (Capanema, 2022b). However, now, this regionalization happens through bidding, with private companies participating.

As the institutional environment matured, the participation of the private sector and investments increased. From 2007 to 2021, the number of municipalities served by the private sector increased from 112 to 850 (AbconSindcon, 2023). Total investments grew from R$11 bi/year to R$18 bi/year in the same period. By comparison, in 1981, the peak of Planasa's investments was R$150/urban inhabitant. In 2022, when total investments reached R$22 bi, investment was R$132/urban inhabitant.

B.2 Inconvenience of septic tank

This appendix provides transcripts collected from Campo Grande newspapers during the period studied. Our objective is to provide evidence that septic tank overflows cause significant inconvenience, harm, and risks to the population's health, mainly due to the characteristic of outcropping groundwater.

"It is tough to live in this situation. Rainwater mixes with sewage, and there are floods here and there. I have four septic tanks to clean and a drain on the side. We bought gravel to put in front of the house to prevent vehicles from passing over the dirty and smelly water. We spend R$700 every three months," reports the resident. (Campo Grande News, 11/16/2016)

"The smell is unbearable. Furthermore, if the rain is hefty, the water enters the houses, exposing us to all types of diseases. It is no wonder we live at the health center."... . "The septic tank fill up very quickly. I have already had to empty mine four times in a year. I had to work to increase its height to the ground level and try to improve the situation. However, some neighbors must empty it every month; there is no way around it," he reports. (G1 Mato Grosso do Sul, 09/30/2016)

"It is the end of a wait of more than 30 years. I have already had to build five septic tanks in my house during this period. There was no longer anywhere to dig a hole", says Santana. (G1 Mato Grosso do Sul, 09/30/2016)

"We urgently need sewage on the avenue. It is a horrible stench; the septic tanks are full, the backyards are flooded with contaminated water, everything is soaked", reports nursing technician Giovanna Barbosa, 35 years old. (Midimax Newspaper, 08/04/2015)

"My life changed. It was a terrible job having to clean the septic tank every month," he says. He says that before the sewage works, he needed to save on water consumed in the bathroom and kitchen, not to mention the insects that infested the house. "Now hygiene is different. I was worried about my grandchildren who come here at home," he says. Regarding the amount paid to the concessionaire, he points out that he spent more hiring a company to clean the septic tank. "Everything has a trade-off, but for the benefit, it is worth it," he believes. (Campo Grande News, 07/10/2015)

"Even though we saved bathroom water, we had to empty the septic tanks every month, which were no longer sufficient," she says. She also says that with complete sanitation in the neighborhood, she is safer regarding her family's health and free from the insects attracted to the septic tanks. (Campo Grande News, 07/10/2015)

For businessman Avelino Amaro, who has had a bar on Rua Elias Nachif for three years, access to the sewage network also brought savings of more than R$100.00, spent on cleaning the site's septic tank. Money that he now invests in products for his business. "As the bathroom was constantly used, I had to clean it almost every week. Not to mention that now we no longer need to apply poison because of the insects," he says. (Campo Grande News, 07/10/2015)

"Here in the region, the water table is very shallow. With small plots of land, many no longer had anywhere to dig septic tanks, and the risk of contamination was high. In addition to health, the work will bring more value to our region. The population is pleased", he highlighted. (The Critic, Campo Grande – 06/02/2014)

"As soon as the work is finished, we will connect. In the yard, we already have two septic tanks that fill up very quickly, and we always need to empty them", commented Felicíssimo Soares. (Campo Grande News, 08/02/2013)

"The septic tank is outside the house, but we know it can contaminate the soil and cause diseases," the resident highlighted. (Campo Grande News, 08/02/2013)

C Details on the Data

C.1 Merging the Data

In this paper, we link three distinct administrative datasets: (*(i)* the sanitation expansion map provided by the concessionaire *Águas de Guariroba*; *(ii)* the birth records from SINASC (System of Information on Live Births); and *(iii)* vital statistics death records from the Mortality Information System (SIM).

C.2 Linkage by Name