Effects of distances on infant mortality in Brazil*

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July 26, 2023

Abstract

Travel distances can affect the delivery outcomes of pregnant women. Using detailed national data from the public health system (SUS), this paper identifies the effect of the distance to the place of delivery on infant mortality between 2006 and 2017 in Brazil. We focus on SUS cases to reduce demand bias because preferences and constraints to join the private system might differ. The paper follows a two-part empirical strategy. First, we focus on a sample of low-risk pregnancies, among which traveling for childbirth would most likely reflect differences in geographic accessibility. Using a linear regression model, we find that moving to another municipality for childbirth increases the infant mortality rate by 17%, and each additional ten kilometers of journey raises the infant mortality rate by 0.1 points per 1000 live births. Results are robust to introducing multiple fixed effects, socioeconomic and risk factors. Second, we use a sample of high-risk pregnancies and a self-made complexity-of-care classification to identify the effect of the distance to specialized medical care on infant mortality. For this sample, the distance to any facility is less relevant than that to facilities with specialized medical technology: living one standard deviation farther away from municipalities with level-II and level-III technologies increases the infant mortality rate by 0.94 and 0.4 points, respectively. Furthermore, the geographic availability of neonatal intermediate and critical care beds is relevant for explaining the effect of the distance to specialized medical care on infant mortality.

*This work was supported, in part by the Bill & Melinda Gates Foundation [INV-027961] and DECIT/MoH Brazil/CNPq [445830/2020-4].

1 Introduction

Many pregnant women, with no alternatives in their hometown, depend on hospitals in other cities to deliver their babies. Travel distances can directly affect health outcomes if moving leads to a reduction in preventive care and care is delayed in emergent or risky situations (Currie and Reagan, 2003; Buchmueller et al., 2006). In childbirth, a procedure that requires a single trip to happen, greater distances can affect maternal and child health if they delay prenatal care, burden mothers with additional travel costs, increase maternal stress during pregnancy[1], jeopardize the informal care provided by family members, or limit the continuity of post-operative care (in the case of cesarean sections, for example).

The effect of travel distances on maternal and infant health at birth can be especially strong in cases which present some level of risk and require specific care or equipment during delivery or postpartum. However, the causal relationship is of difficult identification, as risk and hospital quality likely correlate with traveled distances and maternal-child health outcomes. Nonetheless, identifying these effects is crucial to efficiently design policies related to the geographic distribution of hospitals and health care clinics.

This paper examines the effect of travel distances to the birth location on infant mortality in the public health system of Brazil between 2006 and 2017. We exploit three datasets made available by Data Science Platform applied to Health (Plataforma de Ciência de Dados aplicada à Saúde - PCDaS) (Instituto de Comunicação e Informação Científica e Tecnológica em Saúde, 2022), that gathers information from DATASUS (Health Ministry database). The datasets are the Brazilian Information System of Live Births (Sistema de Informações sobre Nascidos Vivos - SINASC), the Brazilian Information System of Mortality (Sistema de Informações sobre Mortalidade - SIM), and the National Registry of Health Facilities (Cadastro Nacional de Estabelecimentos de Saúde - CNES in Portuguese). We couple these databases with a matrix of inter-municipal distances from de Carvalho et al. (2021), which allows us to identify the distance between municipalities that women travel for childbirth. Ergo, this distance is zero if the mother gives birth in her municipality of residence.

Based on this information, we describe the evolution of travel distances to the municipality of childbirth, identifying that, throughout the studied period, a higher share of women left their municipalities to deliver their babies. Moreover, the average travel distance also increased during this period. We also depict the geographic distribution of health facilities, qualified by the level of perinatal care they offer, showing the striking geographic inequality

[1]The literature suggests that intrauterine conditions and maternal stress during pregnancy can affect health at birth and even well-being in later adult life. (Currie and Almond, 2011; Almond and Currie, 2011; Wadhwa et al., 1993)

in the access to technologically dense services, particularly relevant to save babies at risk.

Our empirical strategy to identify the effect of distance on infant mortality develops as follows. We decided to focus on the sample of mother-child pairs in the public health system to reduce the bias related to the mother's preferences and personal constraints (e.g., income) because, once the mother is in this system, the choice of the place of birth is defined by the health networks' organization. Then, we divided our sample into high-risk and low-risk pregnancies. In this way, we partially exclude the effect of the risk factors on the physician's decision to send a mother for a longer journey, which could impact birth outcomes not because of the traveled distance but due to the complexity of the case. Finally, we exclude observations from municipalities where almost no mother travels to give birth and those with large number of births.

Using the sample of low-risk pregnancies, we estimate a linear regression model of the distance to delivery facilities on infant mortality, including mother and newborn characteristics, pregnancy risk factors plus municipality-of-residence-year and hospital-year fixed effects as control variables. By introducing the municipal and hospital fixed effects, we control for observable and unobservable trends in the place of residence and hospital characteristics. The remaining correlation between the distance and infant mortality approximates causal interpretation. Additionally, we separate the extensive from the intensive margin effect of the distance by using alternative explanatory variables: a dummy if the mother traveled for childbirth, the distance in kilometers, and the distance in kilometers among travelers (i.e., excluding zeros).

The effect of the distance on infant mortality is robust to including all fixed effects and control variables. In the most saturated model, we find that traveling to another municipality for childbirth increases the infant mortality rate by 17%, and each additional ten kilometers of journey raises the infant mortality rate by 0.1 point per 1000 live births. Besides, the effect is coming primarily from deaths happening in the early neonatal period and that are of preventable nature.

In the second part of the results, we focus on the sample of high-risk pregnancies. This sample of mothers would most likely travel because of the underlying conditions of their cases. For this reason, we add a second layer to our analysis: we estimate distances to the closest municipalities with a certain degree of specialized care (levels I to III) rather than the distance the mother effectively traveled. We hypothesize that it is the geographic access to specialized medical technology that is driving the effect of distance on infant mortality for the group of high-risk pregnancies. The physician's decision or the risk profile does not directly affect the distance, making these distance measures more exogenous.

Our results support our initial hypothesis: the distance to any facility is less relevant than that to facilities with specialized medical technology. We find that the distance to level-I facilities, with the most basic technology, has no impact on infant mortality. On the contrary, living one standard deviation farther away from municipalities with level-II and level-III technologies increases the infant mortality rate by 0.94 and 0.4 point, respectively. Furthermore, the availability of neonatal intermediate and critical care beds is relevant for explaining the distance effect on infant mortality.

We estimate the distance effects on different measures of infant mortality and also for the low-risk pregnancy sample. Consistent with our hypothesis, we find that access to specialized technology is irrelevant for low-risk pregnancies. In addition, we find that the effects are concentrated in early neonatal and preventable deaths. This evidence is congruent with the relevant infrastructure being neonatal-specific and with our finding of the effect of the effectively traveled distance on infant mortality for the low-risk sample.

The paper develops as follows. This section contained the introduction. Section 2 summarizes the literature on the effect of distances on mother-child health outcomes. Section 3 describes the data, and Section 4 the institutional setting and background. Section 5 details the empirical strategy for the identification of the effect of distance on infant mortality. Section 6 presents the results, and Section 7 concludes.

2 Literature

Planning the place of birth of a baby is particularly relevant in the context of countries with vast territories with continental dimensions, such as the United States, China, Russia and Brazil. Due to the spatial concentration of health facilities around areas with higher population density, individuals living in more isolated regions, such as rural areas, face high distances and travel times and therefore a higher cost to seek medical assistance. While promising technological advances have occurred in recent years that could mitigate the spatial obstacle to clinical care, such as telemedicine, distance remains important, possibly due to the need for follow-up visits (Chen et al., 2022).

In some regions, distances can be too long, reaching hundreds of kilometers to more developed areas and municipalities. This situation can be exacerbated by the precarious transport infrastructure and lack of motorized transport, which increases the time needed for travel, and is even more pronounced for low-income populations that inhabit the peripheries (Weiss et al., 2020). Thus, people who have to face long distances are discouraged from seeking care when needed.

To isolate the causal effect of distances on health, the literature often resorts to empirical strategies that explore spatial variations due to the closure of health facilities at some point in time. The closing of these units can be interpreted as shocks in the distances to be covered by patients to the health unit closest to their residence. Buchmueller et al. (2006) finds evidence that hospital closures lead to greater distances being traveled by patients, which consequently leads to an increase in the mortality rate from heart attacks and unintentional injuries. Even in the case of the need to travel for specific surgeries, in which it is possible to plan the trip in advance, greater distances harm the patient and increase mortality rates (Chou et al., 2014). Avdic (2016) and Avdic et al. (2019) analyze the impacts of such closures on health outcomes, which could be positive if increasing distances is accompanied by a consolidation of complex establishments and improving quality.

There is also evidence to suggest that distances to clinics that provide services matter to the point where they critically affect family planning, influencing both teenage pregnancy and the decision to have an abortion. Branson and Byker (2018) show that teenagers who lived close to clinics of an initiative aimed at reducing teenage pregnancy delayed pregnancy, completed more years of schooling, and earned higher salaries than those who lived farther away from these clinics. In Madagascar, a community-based intervention was proved efficient to reduce "cost of remoteness" and fertility (Herrera-Almanza and Rosales-Rueda, 2020). The literature that studies the effects of distances on abortion practices is focused on the effects arising from exogenous shocks of restrictions on the operation of abortion clinics in the United States (Fischer et al., 2018; Lu and Slusky, 2019; Lindo et al., 2020; Myers, 2021). The result set indicates that increasing distances to abortion clinics due to clinic closures decreases abortion rates and increases local fertility rates.

Similarly, greater distances to clinics reduce the demand for preventive care among children and mothers (Currie and Reagan, 2003; Lu and Slusky, 2016). Less proximity in the access to preventive care reduces the performance of preventive maternal health exams. On the other hand, the proximity of access to health services, specifically to a supplemental nutrition program, is associated with higher pregnancy weight, higher birth weight, and the probability of initiating breastfeeding at the time of hospital discharge (Rossin-Slater, 2013). These effects are higher among lesser-educated mothers[2]. In general, evidence indicates that distance to care matters for the patient's health, but its results and magnitude will depend on the nature of care and the degree of urgency of the procedure.

Other factors influence how distances affect final outcomes. Following Adhvaryu and Nyshadham (2015), distance served an instrument for exogenous variation interacted with

[2]Better access to schools - including constructing new units - does affect fertility and child mortality as well (Grépin and Bharadwaj, 2015).

rainfall, leading to an additional cost for traveling. The quality of roads itself serves to this purpose: Aggarwal (2021) found a road pavement program impacted antenatal visits and fewer miscarriages, that eventually led to a rise in infant mortality by delaying demises to post-birth.

In Brazil, the technical recommendations of health units and equipment in the national health system, *Sistema Único de Saúde* (SUS), generally follow a normative character and use population parameters as a reference for calculation and planning (Ministério da Saúde, 2015). This method follows the logic of population density, potentially reinforcing preexisting social and spatial inequalities. As a result, the North and Midwest, less developed and populated regions, register the highest rates of distances to travel and travel time (Weiss et al., 2020). At the local level, spatial segregation is still present, given that high-complexity health facilities tend to be more concentrated in central regions of cities, so that the peripheral population has lower accessibility (Pereira et al., 2019).

Travels are also present in childbirth: almost a third of births in Brazil occur in municipalities other than the mother's residence (Pinho Neto et al., 2023). The percentage of pregnant women commuting to give birth has increased recently, a movement that has been accompanied by an increase in the average distances covered. These same trends hold for the remaining infant mortality cases (Pinho Neto et al., 2023).

This article is part of the literature that studies the effects of distances traveled to perform childbirth on maternal and infant health, specifically neonatal mortality. Our contribution to this branch of research is twofold. First, we provide a novel setting to the analysis of this phenomenon as Brazil is one of the largest public health system of the world with a vast territory. Second, contrary to previous studies, we use two different distance variables, the effectively traveling distance and the distance to the closest facility, and find differentiated impacts contingent on pregnancy risks. When pregnancy risks are low, the former variables plays a major role and the latter is irrelevant. However, if pregnancy risks are high, the proximity to specialized care emerges as more salient. Particularly, Level-II and Level-III infrastructure inputs (intermediate and critical neonatal beds) are relevant for explaining the effect of the distance to specialized care on infant mortality.

3 Data

To elaborate our investigation, we leveraged three datasets made available by Data Science Platform applied to Health (Plataforma de Ciência de Dados aplicada à Saúde - PCDaS) (Instituto de Comunicação e Informação Científica e Tecnológica em Saúde, 2022), which gathers information from DATASUS (Health Ministry database). First, the Brazilian Information System of Live Births (Sistema de Informações sobre Nascidos Vivos - SINASC) records every woman accessing perinatal services in Brazil with complementary description of socioeconomic variables and medical conditions[3].

Combined with this, the infant death registry, i.e., mortality from the Brazilian Information System of Mortality (Sistema de Informações sobre Mortalidade - SIM), also reported by the Brazilian Universal Health System, contains demises and their causes according to ICD-10 code. The focus of this analysis is the distance from residence to birth and its implications, though a second travel (between birth and another facility, sometimes where maternal or infant death takes place) was detected during study. One should avoid, however, any inferences on these women's preferences on travels and facilities as, in Brazil's Universal Health System, public servants might provide directions on where to attend, so it is not clear whether pregnants get to choose destinations (Viellas et al., 2014). We discuss distance measures and sources in subsection 3.2. The match of these datasets engenders about 35 million observations. Note that this analysis does not cover births which happened at home or other establishments, only health facilities.

Finally, there is the National Registry of Health Facilities (Cadastro Nacional de Estabelecimentos de Saúde - CNES in Portuguese). It supplies data on installed capabilities - infrastructure, equipment and human resources - of the universe of health facilities, either public, private or mixed (Brazil. Ministerio da Saúde, 2022). We concentrate our attention on facilities that delivered 50 births per year at least once between 2006 and 2021, and provide services in the public health system, the SUS system (Sistema Único de Saúde in Portuguese)[4]. After applying these filters, we remain with a panel that contains 3611 health facilities; approximately, 2900 facilities per year, with 2277 complete cases (63%), i.e., present every available year. We have enriched this information by developing a classification of level of care, which we detail below.

3.1 Classification of levels of care

Although CNES has its own classification, it embodies many specialties, while ours is exclusive to maternal and neonatal services. After looking into Ministry of Health (MoH) requirements, we define levels based on three components: infrastructure, equipment, and

[3] https://pcdas.icict.fiocruz.br/conjunto-de-dados/sistema-de-informacao-sobre-nascidos-vivos/

[4] Given the hybrid model existing in Brazil, we defined a parameter to consider a facility as belonging to Universal Health System (SUS): 85% of its obstetric beds must be exclusive for SUS patients. In the absence of obstetric beds, we marked those with formal vinculation to the system, unrestricted to perinatal or related services.

human resources. The criteria for each level and domain were set as follows:

- **Level I**: Adequate for low-risk births. For *infrastructure*, it demands at least one pre-labor, labor and post-labor room or bed. In terms of *human resources*, it needs at least one health professional qualified to assist eutocic deliveries and one nurse technician. Finally, having basic life support fulfills *equipment* guidelines.

- **Level II**: This type is suitable for high-risk births requiring obstetric surgical interventions and intermediate neonatal care. Human resources embody surgical team and pediatrician, while infrastructure corresponds to surgical obstetric beds and neonatal intermediate care beds. Incubators, ultrasound and phototherapy machines encompass needed equipment at this degree.

- **Level III**: Obstetric or neonatal critical care cases should be directed to this level, in which assistance is given by a more comprehensive health staff, with phonologists and physical therapists among others. Presence of NICU and ICU is also a criterion to meet.

Assuming the components infrastructure, human resources, and equipment are complementary, a certain facility was classified only if presented the requirements for all components simultaneously. Otherwise, it remained at the minimum level among components. We assigned a *Level 0* category for any establishment that was not classified in any of the previous levels of care. Overall, we are able to analyze each component separately and taken together. Additionally, due to a restriction on human resources data beginning in 2012, there are two versions of the aggregate index: the first starts in 2007 and has the available components (equipment and infrastructure) while the second is from 2012 onwards, with the full set (See Pinho Neto et al. (2023) for more details). In this paper, we use the classification that spans for the whole period of analysis as one of our primary variables. Hence, the classification only takes into account infrastructure and equipment information.

Following this procedure, we compared our perinatal-specific classification with the Ministry of Health's general classification, as one would expect both to keep a strong affinity. Other suggestive evidences are volume of births and allocation of very high-risk births (either preterm or low birth weights)[5]. Literature has established a positive relationship between these variables and degree of specialization in medical care (Lorch et al., 2021; Brazil. Ministerio da Saúde, 2012). Indeed, this holds as shown in Table A.1 and confirms the reliability of our measure.

[5]Very preterm births are those with 22 weeks or less of gestational age. Babies with very low birth weights are those with 1500 grams or less of weight at birth.

3.2 Distance measures

Distances traveled by mothers and distances to facilities and inputs were obtained from de Carvalho et al. (2021). These allow an assessment on the intensive margin of travels, rather than a simple moved or did not move comparison. This procedure takes geographic coordinates (latitude and longitude) of each municipality's downtown neighborhood and runs package *OSM* from *OpenStreetMap* in R software, returning kilometers of travel on public roads. de Carvalho et al. (2021) undertakes these tools applied to the universe of Brazilian municipalities (5570) and traces every combination (5570x5570). Thus, we obtained the (approximate) distance between every municipality pairing that a pregnant woman went through in Brazil dated from 2006 to 2017.

Our dataset also includes minimum distances to health facilities, infrastructure, equipment and human resources by perinatal level of care (e.g. the distance to a Level III facility) and each health separate input (e.g. the distance to ICU beds). First, starting from (de Carvalho et al., 2021), we eliminate combinations whose distances were greater than or equal to 2000 kilometers for computational reasons. Second, for each municipality of origin (residence), we keep the destinations where the facility or health input of interest is available. In this step, they are not restricted by demand or supply factors, such as past deliveries or public authority guidelines. At last, we identify the closest possibility among the remaining options[6].

4 Institutional Background

This section describes the accessibility to health services and its relation to infant mortality from two perspectives: demand and supply. First, we briefly describe the organization of the Unified Health System in Brazil, and, using a classification of levels of perinatal care, we show the geographic distribution and access to health facilities with different qualifications. Then, we describe the distance mothers travel to give birth and how it is correlated with their socioeconomic background and risk factors. Finally, we show the slow-down in infant mortality fall in the last decade, and suggestive evidence of the role of the distance to health facilities in the reduction of infant mortality rates.

[6] When calculating averages which aggregate in broader geographic levels, we opted to weight by the count of births of hosting municipality.

4.1 The Health System

Brazil's Unified Health System (*Sistema Único de Saúde* or SUS in Portuguese) is the largest public health system in the world, taking care of 190 million people (UNA-SUS, 2021). Over its 32 years of life, the SUS evolved from a decentralized organization of healthcare to the regionalization of these services (Viana et al., 2018). The family health strategy, which focuses on primary healthcare, was the strategy used to implement the SUS, particularly between 1988 and 2000. During this period, public healthcare expanded access to basic health services to vulnerable populations even in remote geographic regions (Viacava et al., 2018). Investment and management of health services relied more on municipalities than before, which became a limitation for the continuity of care and access to hospitals (Viana et al., 2018).

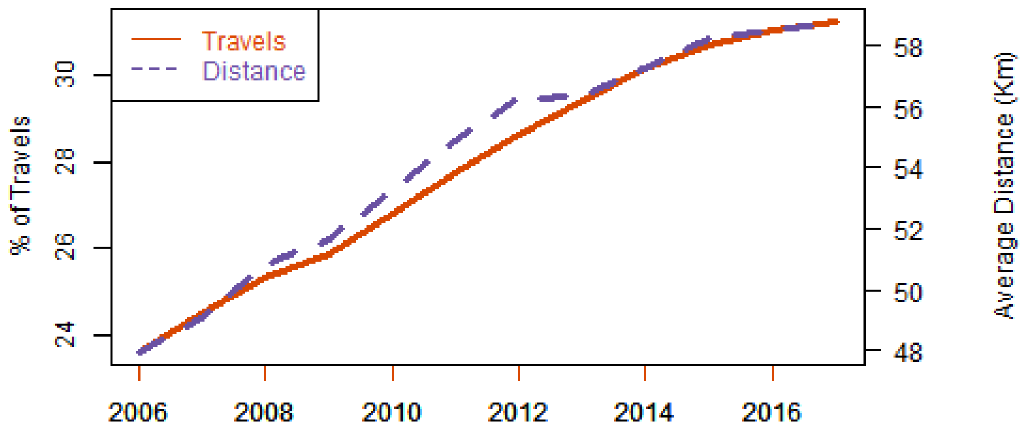
The regionalization of health services started in 2000. The health services were organized in networks that surpassed municipal limits. A health network is an organization of health services and actions of different technological densities, integrated by technical support, logistics, and management systems, that guarantee integrated care. Health networks provide services in three healthcare areas: primary, specialized, and emergency care. In addition, health networks have three levels of care, which vary by technological density: low (primary healthcare facilities), medium (secondary healthcare facilities), and high (hospitals) (Ministério da Saúde., 2010). Currently, regionalization is still a working process. The considerable variation in geographic conditions, particularly population density, reduces the effectiveness of health networks. In places with low-density populations, coordinating and organizing services with different technology densities that guarantee the continuum of care is a challenge (Bousquat et al., 2019).

4.2 Access to Health Facilities for Birth in Brazil

Between 2006 and 2017, the fraction of women giving birth in another municipality and the traveling distance increased. The average distance pregnant women travel to give birth changed from 48 to 59 kilometers, whereas the fraction of women that traveled also moved from 23 to 31 percent (See Figure 1). Several reasons could explain why women have increasingly been moved to farther locations. Pregnant women may travel more because of changes in pregnancy risk profile, socioeconomic conditions, or health services availability and organization.

The mother-child risk profile could partially explain why women traveled more over the decade. Consistent with the literature, pregnant women and newborns at risk tend to travel

Figure 1: Share of travelers and traveling distance



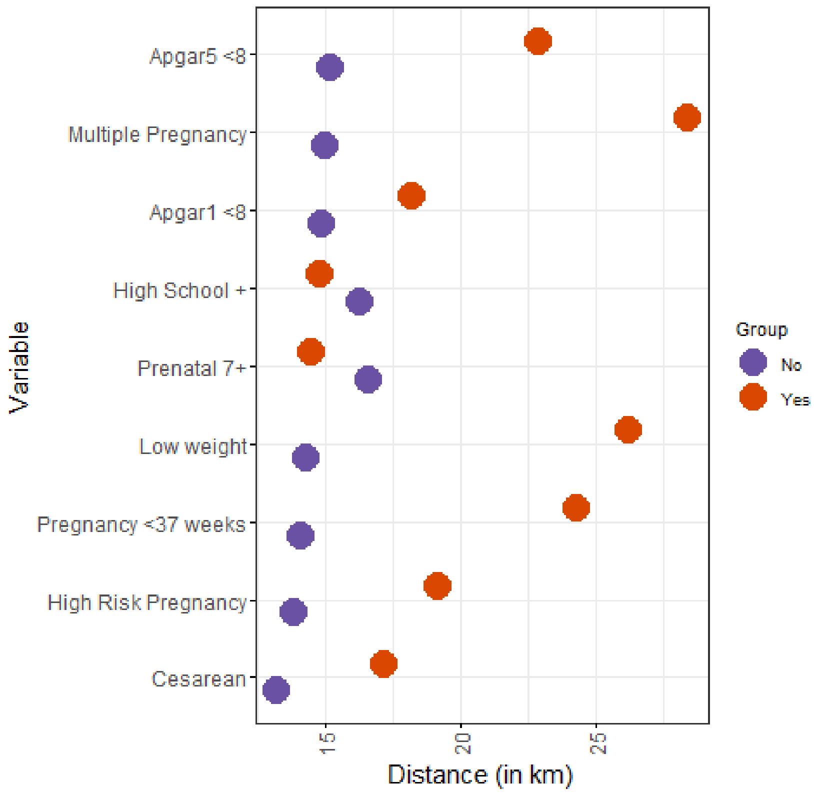
Note: Figure shows share of women who travel for childbirth (LHS - in %) and the average distance conditional on traveling by the same group (RHS - in kilometers) at the national level ranging years 2006 to 2017. *Source*: Pinho Neto et al. (2023)

more than their low-risk counterparts. Figure 2 shows that the distance women traveled for childbirth was higher among those with multiple pregnancies, high-risk pregnancies, low-weight newborns, and newborns with low APGAR scores. On the other hand, education and prenatal controls do not correlate with longer paths to another municipality to give birth.

Municipal socioeconomic characteristics vary with the distance mothers travel. Distances tend to be shorter with increasing levels of development. Figure 3 displays OLS coefficient of socioeconomic characteristics on the traveled distance. All variables are standardized, so coefficients should be interpreted as changes in kilometers per one standard deviation. Each dot represents a coefficient: orange dots indicate negative relationships and purple dots positive ones. The largest coefficients are per capita income and Human Development Index (HDI)'s education and income components. One additional standard deviation in these variables reduces the distance pregnant women travel by at least 10 kilometers. Analogously, women in poor municipalities travel longer distances than women in less poor locations. Employment rate, life expectancy, access to electric power, water, and sanitation are negatively correlated with the distance women traveled, though their effect is smaller than that of the previous variables.

Correlated with municipal socioeconomic characteristics, distance mothers travel to give birth also presents regional inequalities. The highest share of mothers traveling is in the Northeast and Southern states, but the distance traveled by these mothers is among the shortest. On the contrary, mothers in the North and Central-west regions tend to give birth at their municipality of residence. Still, they travel the largest distances in the country. This

Figure 2: Individual factors and moving status



Note: Figure shows the average distance of pregnant women traveling to another municipality for childbirth (x-axis) by the presence of individual factor (y-axis list, Yes in orange and No in purple).
Source: Pinho Neto et al. (2023)

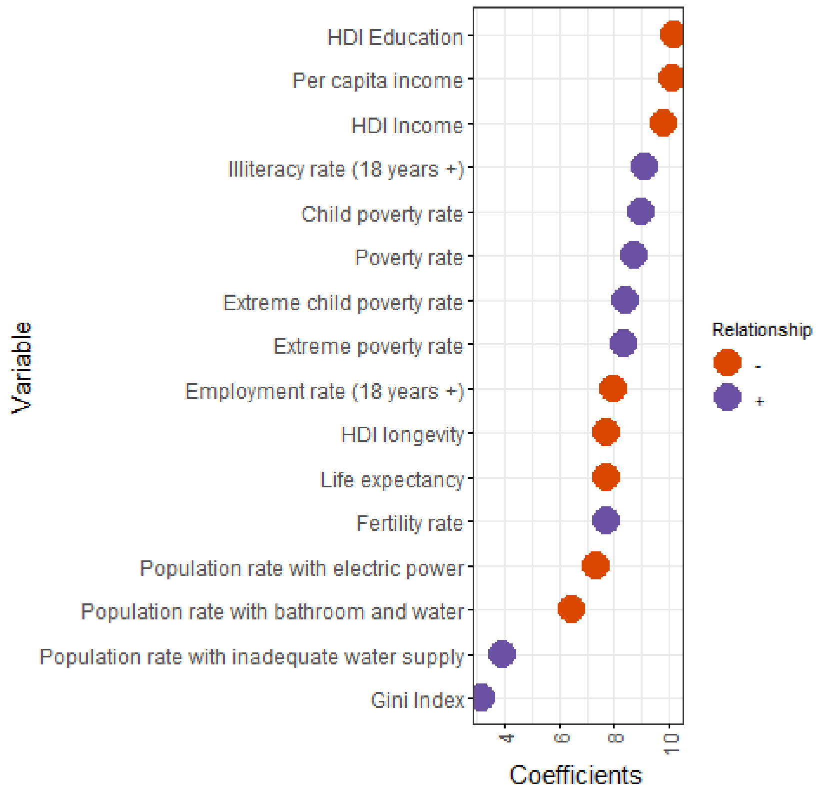
geographic pattern changed little between 2006 and 2017 (Pinho Neto et al., 2023).

4.3 Availability of Health Infrastructure for Newborns

Figure 4a shows the evolution of the number of facilities by the level of perinatal care between 2007 and 2021. Facilities with higher technology density - levels II and III - are scarcer than other facilities, which is expected because high-tech inputs, e.g., NICUs and ventilators, usually concentrate in high-volume facilities in high-density areas. Levels II and III facilities increased over time but, by 2021, had not fully covered their expected demand. As shown in Figure 4b, in 2007, only 54% of very preterm births happened in level-III and level-II facilities. Despite more of these facilities being available in 2021, still, 29% of the very preterm newborns were not born in them.

Figure 5 depicts with a color palette the distance to the closest health facility with

Figure 3: Socioeconomic factors and distance



Note: Figure shows estimated coefficient magnitudes (x-axis) of each socioeconomic factor (list on y-axis) regressed separately at the municipal-level against average traveled distance for 2010 cross-section. Colors indicate the signal of correlation: negative in orange and positive in purple.
Source: Pinho Neto et al. (2023)

a certain level of perinatal care: The darker the color, the larger the distance, and vice-versa, the lighter the color, the shorter the distance. If we focus on the distance to level-III facilities, we observe that light colors are primarily concentrated in cities on the eastern coast. In contrast, the North and Central-west regions are in the darkest color. In terms of magnitude, mothers from the latter regions would have to travel more than 250 kilometers to give birth in a level-III facility, which is one-tenth of what they would have to travel living in a coastal city. Despite the drastic geographic contrasts, we observe a mild improvement in the access to level-III facilities, consistent with the increase in their number between 2007 and 2021 (Figure 4).

Level-II facilities are more accessible than level-III facilities. Figure 5 shows that not only mothers from the coast but also from Central-west and North regions live close to level-II facilities. Besides, the distance to these facilities reduced over time. Level II has obstetric surgical beds and intermediate care units. Thus, we can infer that access to this infrastructure is more equitable than access to NICUs or other level-III infrastructure.

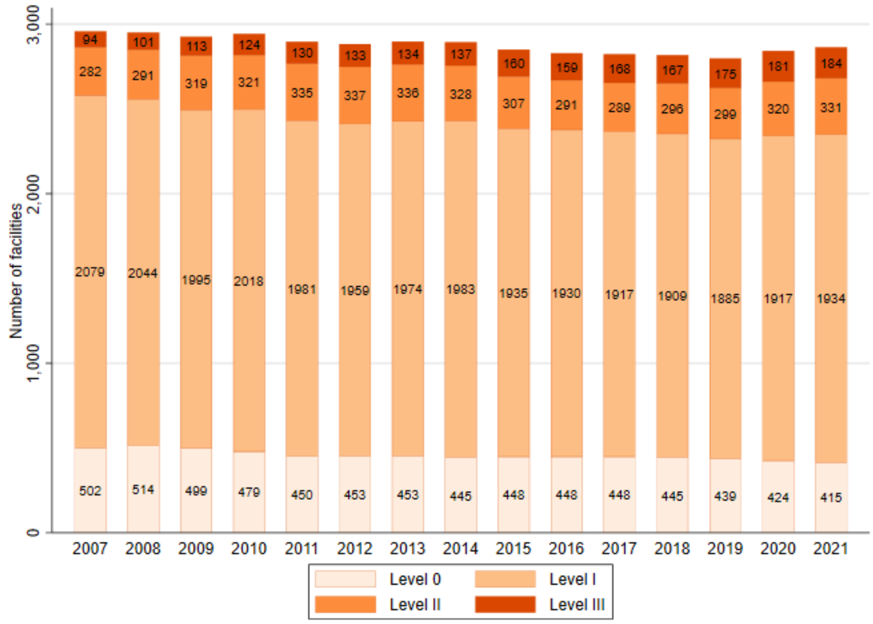
The classification of health facilities by level of care considers infrastructure and equipment items. Although these items tend to evolve in parallel, some are less accessible than others. For instance, the minimum distance to level-II and level-III infrastructure is longer than the minimum distance to most equipment. Pathological newborn and obstetric surgical beds (level III infrastructure) remained with a similar minimum distance between 2007 and 2021. Nevertheless, the minimum distance beds in NICU (level III) and beds in intermediate care units (level II) reduced significantly in the same period. In the former case, the average distance changed from 145 in 2007 to 103 Km in 2021. In the latter, the average distance changes from 98.8 to 60 Km over the same period (See Pinho Neto et al. (2023) for more details of minimum distances to equipment, infrastructure, and human resources).

4.4 Infant Mortality Rates in Brazil

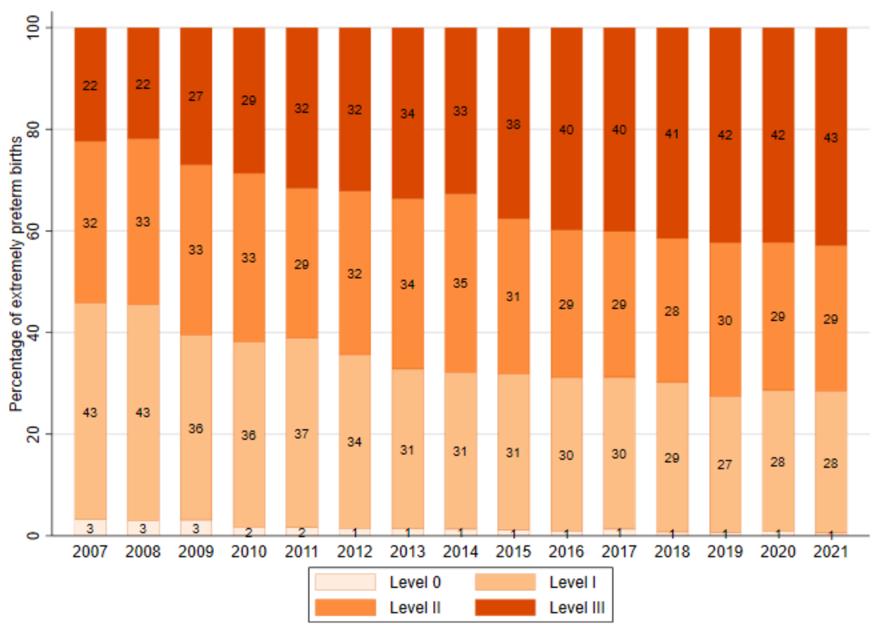
Despite the improvements in child health in the last 30 years, the decrease in infant mortality in Brazil slowed down over the last decade (Leal et al., 2018). Most infant mortality reduction came from post-neonatal deaths such that, between 2006 and 2017, neonatal deaths became the main infant mortality component (Bernardino et al., 2022). Figure 6 shows that infant mortality reduced only mildly between 2006 and 2017 (black line). Infant mortality is classified by the age and the cause of death. Trends are similar for all series. The largest components are early neonatal (the first week after birth) and preventable deaths, i.e., dark orange and purple lines. Among preventable causes of death, bacterial sepsis and respiratory distress syndrome were the most frequent (Pinho Neto et al., 2023). These conditions could be avoided by adequate care for women during pregnancy and birth (Leal et al., 2018), making access to health services a relevant matter.

Figure 7 presents suggestive evidence that the distance to health facilities matters for children's survival. Panel (a) shows that the probability of death in the first year of life is 0.5 percentage points higher for children with mothers that traveled to give birth. Furthermore, panel (b) displays different death curves that change with the distance traveled. Thus, the probability of death is close to 2 percentage points lower for children whose mothers traveled between 1 and 50 Km instead of more than 100 Km.

Figure 4: Evolution of facilities and births by perinatal level of care (2007-2021)



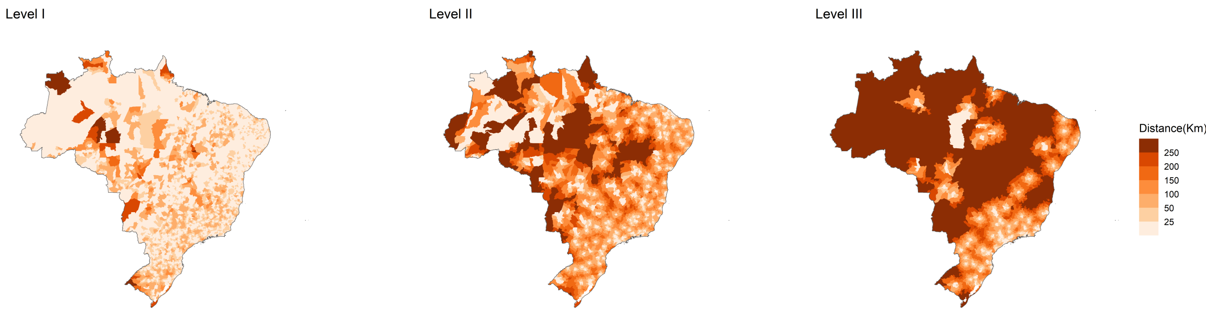
(a) Facilities



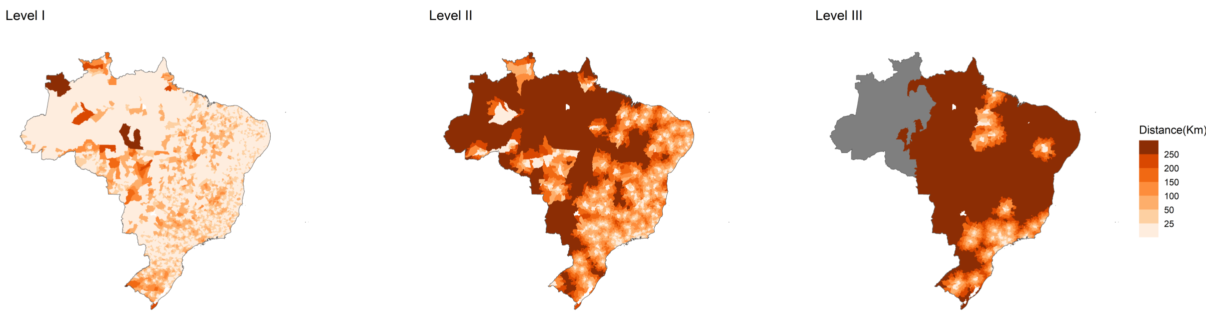
(b) Very preterm births

Note: Figure shows time trends for number of facilities (panel a) and composition of extremely preterm births (panel b) by levels of care. Level I: A facility capable of assisting low-risk births. Level II: A facility capable of assisting high-risk births requiring obstetric surgical interventions and intermediate neonatal care. Level III: A facility capable of assisting high-risk births requiring obstetric or neonatal critical care. Level 0: Residual level, not satisfying any of the criteria above.
Source: Pinho Neto et al. (2023)

Figure 5: Municipal maps of minimum distances to health facilities by perinatal level of care



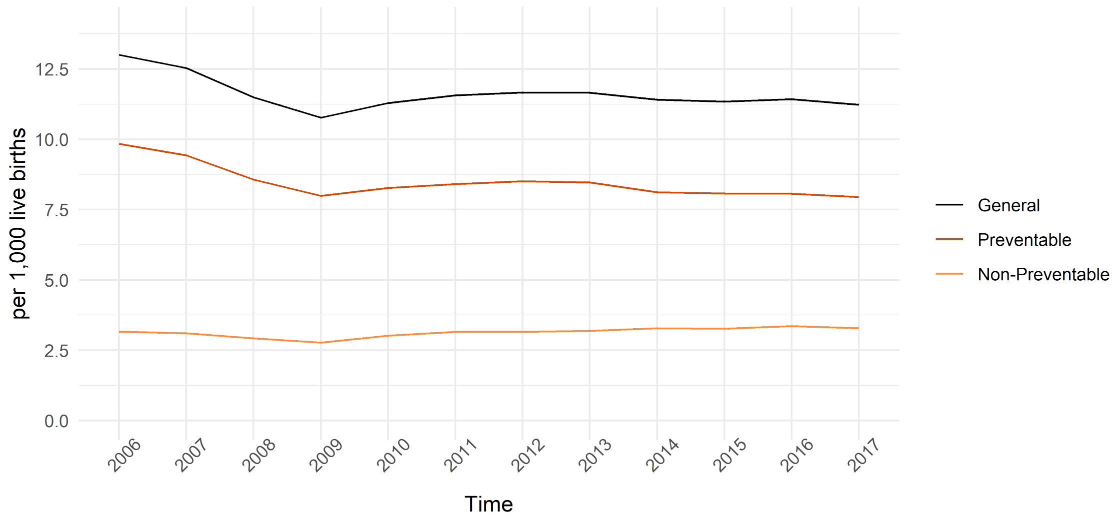
(a) 2021



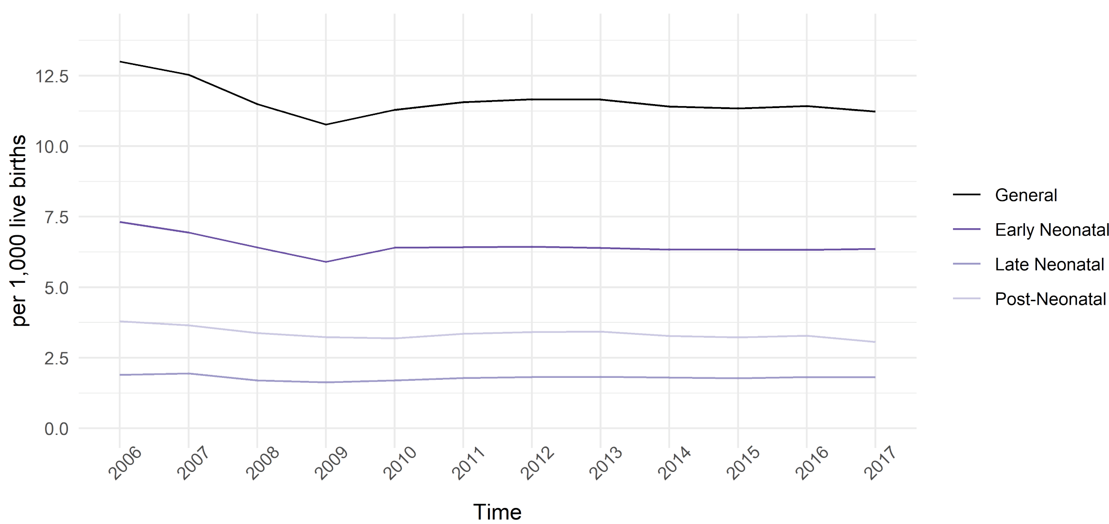
(b) 2007

Note: Figure shows the shortest traveling distance between one municipality and another containing a facility of a certain level of care in 2021 (top panel) and 2007 (bottom panel). Light colors represent shorter distances, while darker are longer routes. Gray areas are over 2000 kilometers away from facilities. Level I: A facility capable of assisting low-risk births. Level II: A facility capable of assisting high-risk births requiring obstetric surgical interventions and intermediate neonatal care. Level III: A facility capable of assisting high-risk births requiring obstetric or neonatal critical care.
Source: Pinho Neto et al. (2023)

Figure 6: Infant mortality rate national trends by age and preventability of death cause



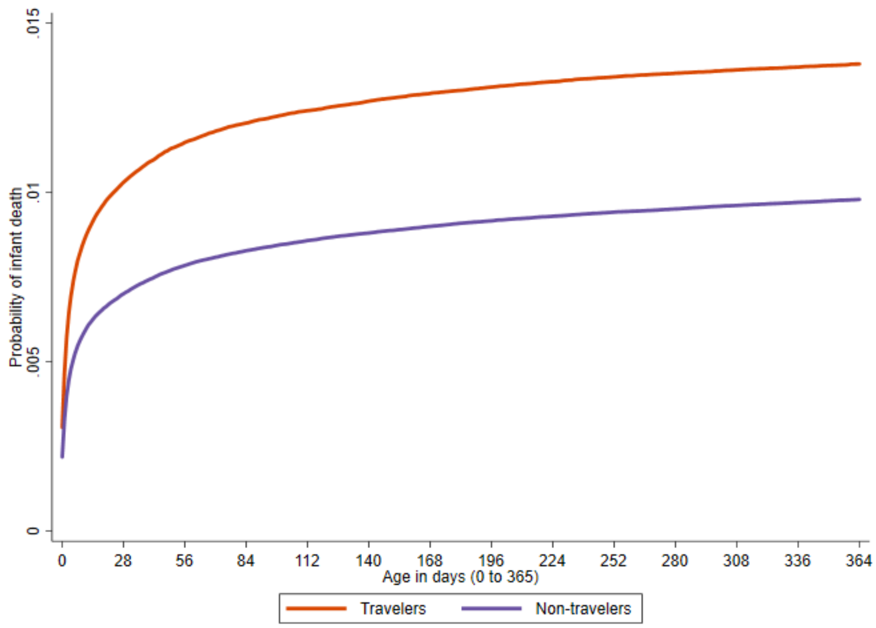
(a) Cause of death



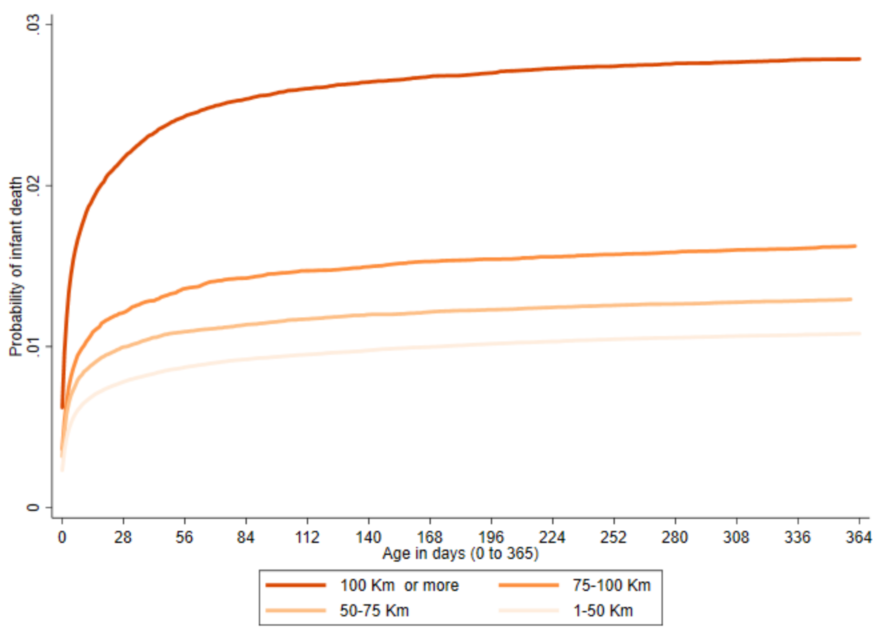
(b) Age of Death

Note: Figure shows time trends for each type of mortality from 2006 to 2017. Black line represents General Mortality and others are decompositions. Preventable (dark orange) and Non-Preventable (light orange) refer to cause of death (panel A). Early Neonatal (dark purple), Late Neonatal (light purple) and Post-Neonatal (lilac) refer to age of death (panel B).
Source: Pinho Neto et al. (2023)

Figure 7: Mortality curves of children under one year of life by distance to place of birth (2017)



(a) Travel vs No travel



(b) By traveled distance

Note: Figure shows probability of death (y-axis) by age of child in days (x-axis) for 2017. Panel A splits sample in travelers (orange line) and non-travelers (purple line). Panel B disaggregates travelers by distance intervals in shades of orange, with 100 kilometers or more in dark orange and less than 50 kilometers in light orange.

5 Empirical strategy

We are interested in identifying the effect of the distance to delivery facilities on infant mortality. As explained in the data section, the distance is estimated at the municipal level, i.e., between the municipality of residence and the municipality of the delivery facility. If a mother lives and gives birth in the same municipality, the distance she travels is zero. The dependent variable is infant mortality, presented aggregated and disaggregated by age and preventability of the cause of death.

A positive association between distance and infant mortality does not imply a causal relationship because observable and unobservable confounders could be sources of bias:

1. Mothers' socioeconomic characteristics may affect their demand for healthcare, i.e., the choice of a health facility to give birth and the distance traveled, and also be correlated with the child's outcome.
2. The distance to facilities increases with the complexity of care. Hospitals receiving the most complex cases are fewer in number and farther apart, partly due to the organization of health networks. Thus, we observe mothers and children with risk factors traveling longer distances and dying more because of the complexity of their case, but not because the distance increased their mortality.
3. Municipal socioeconomic characteristics, such as living conditions, income, and education, could simultaneously affect mortality and distance to health facilities.

We take advantage of the organization of the health system to isolate the causal relationship between the distance to delivery facilities and infant mortality. We focus on the sample of mother-child pairs in the public health system, i.e., cases where childbirth happened in a public health facility. In this manner, we reduce the bias related to the mother's preferences and personal constraints (e.g., income) because, once the mother is in the system, the choice of the place of birth is defined by the health networks' organization.

In the health system, a screening process during pregnancy determines the facility where childbirth should happen: high-risk pregnancies deliver children in facilities with a high complexity of care; the opposite occurs with low-risk pregnancies. Since the expected distance to a health facility depends on the complexity of care, we split the sample in two: Low-risk and high-risk pregnancies. Parent-child pairs with at least one pregnancy risk belong to the second group, and the rest belong to the first[7]. Finally, we exclude observations from

[7] Variables considered: patient age below 18 and above 35, presence of abnormalities, multiple pregnancy and prematurity.

municipalities where almost no patient travel to give birth and those with many births. We consider municipalities in the bottom travel share quintile, as they are outliers in the patterns of travels, and the top birth quintile because they already have access to medical technology, hence parents do not require to travel to another municipality to give birth.

Low-risk pregnancies should result in eutocic births, which require minimal medical assistance. Thus, the distance traveled to give birth would depend more on geographic factors than the pregnancy risk profile[8]. We estimate the following model for this sample.

$$IM_{imht} = \beta D_{imht} + \alpha_{mt} + \phi_{ht} + \theta X_{it} + \epsilon_{imht}, \tag{1}$$

where IM_{imht} is a dummy variable that equals 1 if the child i died in year t; D_{imht} is the distance between the municipality of residence m and the municipality where the delivery facility h is. X_{it} includes socioeconomic characteristics of mother and child. α_{mt}, ϕ_{ht} are municipality-time, hospital-time fixed effect interactions.

Municipality and hospital fixed effects reduce another source of bias. Mothers and babies are not randomly located; the place of origin and destination also correlate with their socioeconomic background. Children with mothers living in poorer municipalities are less likely to have access to health services and, at the same time, be more susceptible to illness and death. By introducing the fixed effects, we control for observable and unobservable trends in the place of residence and hospital characteristics. The remaining correlation between distance to facilities and infant mortality, measured by β, approximates the effect of interest to a causal interpretation.

We estimate two variations of equation (1). First, we exchange the distance variable with an indicator that signals if the mother traveled to the health facility. This variable approximates the extensive margin of the traveled distance, i.e., the decision to travel. Second, we restrict the sample only to the mothers that traveled a positive distance, isolating the intensive margin of the traveled distance. In each specification, we analyze the robustness of β, by gradually including all control variables. The changes in β after the inclusion of a certain control variable could indicate the sign of the bias related to that variable omission, which could vary between intensive and extensive margin distance measures.

We expect the sample of high-risk pregnancies to travel long distances because of their underlying conditions. Furthermore, we posit that the distance to a facility is as relevant

[8]Card et al. (2019) use a low-risk first birth (LRFB) sample to identify the effect of c-section on children's health after birth. There are no clinical indications for performing a c-section on LRFB mothers. Hence, if it happens, it would be related to hospital medical practices, which is the effect they wanted to capture. Drawing a parallel to our case, we expect that the association between distance and infant mortality would less likely be attributed to the risk profile in the low-risk sample.

as access to specialized medical technology in reducing mortality in this group[9]. Therefore, we use distances to the closest facilities providing levels of care I, II, or III as our main explanatory variables. The distances depend on the geographic location of the municipality of residence and the municipalities where the closest facilities are. Thus, the health network decision and risk profile do not affect the distance directly. On the other hand, as mothers not necessarily traveled those distances for childbirth, the effect of the proximity to relevant health services on infant mortality must be interpreted as an intention to treatment effect.

The regression model we estimate for the high-risk sample is the following.

$$IM_{imt} = \alpha + \omega_1 DLI_{mt} + \omega_2 DLII_{mt} + \omega_3 DLIII_{mt} + \theta X_{it} + \phi M_m + \delta_t + \epsilon_{imt}, \qquad (2)$$

where DLI_{mt}, $DLII_{mt}$ and $DLIII_{mt}$ are the distances between the municipality of residence m and the closest municipality with a level-I, level-II or level-III facility, respectively. For comparability purposes, all distances are normalized with respect to their means and standard deviations[10]. IM_{imt} is defined as in equation (1), δ_t are year fixed effects, X_{it} includes mother and baby characteristics and pregnancy risk factors, and M_m are municipal characteristics, such as the HDI, literacy, poverty or access to basic services. After controlling for individual and municipal characteristics, we expect to get closer to a causal interpretation of the effect of distance on infant mortality in high-risk cases[11].

The coefficients of the main explanatory variables of equation (2) - ω_1, ω_2 and ω_3 - measure the additional effect of the distance to a certain level of care on infant mortality after taking into account the effect of the other levels of care. We choose a specification that simultaneously contains the three distance variables because we observe a correlation between them, i.e., destinations with level-II facilities also tend to have level-III facilities. In addition, we estimate specifications similar to (2) that introduce each variable separately and test for other measures: distance to the closest set of equipment and human resources by the level of care, distance to the closest infrastructure for obstetric and newborn care (e.g., beds in NICU, obstetric surgical beds). These estimations help us understand the effect captured

[9]Empirical evidence supports that access to medical technology improves birth outcomes of low-birth-weight and premature babies, particularly access to neonatal intermediate and intensive care units (Lorch et al., 2021).

[10]In our estimation sample, one standard deviation for level I equals 24 kilometers. For level II, 129 kilometers and, for level III, 282 kilometers.

[11]We decided not to introduce municipal fixed effects for two reasons: First, the main explanatory variables vary at the municipal level, i.e., all mothers within a municipality have the same geographic access to the different facilities. Second, despite the average reduction in the distance to level-II and level-III facilities over time, we have yet to observe significant changes in the geographic disposition of these facilities. Thus, the within-municipal variation is small, preventing us from perfectly separating fixed-time municipal unobservables from geographic distance-related factors.

by the distance variables in more detail.

6 Results

6.1 Low-risk pregnancies

Table 1 reports the regression coefficients of distance on infant mortality for the low-risk-pregnancy sample. The explanatory variable in Panel A is an indicator that equals 1 if the mother traveled to another municipality for childbirth. Panel B shows the effect of distance itself in a 10 kilometers scale, while in Panel C, distance is conditional to traveling mothers, i.e., includes only positive distances.

The first column of Panel A, Table 1 shows the estimates of equation (1) with no controls or fixed effects: Traveling is associated with an increase of 0.27 infant deaths per 1000 live births or 0.27 points in the infant mortality rate[12]. As we include the mother and newborn's controls, such as education, race, marital status, weight at birth, and APGAR index, this number falls in half: 0.16 points. This is due to the association between having to travel and these characteristics, e.g., poor education and illiteracy, which impact infant mortality next. Column 3 shows that introducing variables related to pregnancy risk does not change the effect, which is expected because the sample is of low-risk pregnancies. Finally, columns 4 and 5 include fixed effects for hospital-year and municipality-year levels. While the former implies a coefficient reduction (to 0.12), the latter results in an upsurge: traveling is now associated with an increase of 1.03 points in the infant mortality rate, a 17% increase. Hence, the trend of mother's residence living conditions largely explains the changes in infant mortality rate. Once we take these effects into account, the distance effect increases significantly.

Panel B results show the increase in infant mortality associated with an additional 10-kilometer distance to the delivery facility. Column 1 indicates this association is 0.16 points in magnitude. The inclusion of controls follows the pattern of Panel A, with a lower level starting in column 2 and a small peak in column 5, our preferred specification. In this case, being extra 10 kilometers farther from the delivery facility is associated with an increase of 0.11 points in infant mortality rate, a 2% increase.

Lastly, we restrict the sample to travelers (Panel C), which reduces the observations from 10.2 millions to 3.8 millions, a 37% of the total. Results change little compared to the previous panel. The major change is between columns 1 and 2; the remaining specifications cause finer adjustments to magnitude. Mother and newborn variables control most of the

[12]Henceforth, we describe the results as infant mortality rate point changes for parsimony.

confounding effects correlated with distance. Column 5 estimate is slightly smaller in Panel C with respect to Panel B.

Results show that the distance a mother travels for childbirth increases infant mortality. However, the extensive margin, i.e., to travel or not, is more relevant than the intensive margin, i.e., the traveled distance. The infant mortality rate increases by 1 point if the mother moves to another municipality to give birth and by 0.1 points for every ten additional kilometers she travels. Mothers would have to travel 100 km to increase infant mortality by 1 point, twice the average distance (52 km).

Table 2 is structured as Table 1, and panels correspond to which explanatory variable we focus. The specification is the same for all columns, containing the same regressors as column 5 of Table 1. Each column is a type of mortality measure. Column 1 presents infant mortality results, replicating Table 1. Columns 2-4 consist of infant mortality by the age of death: Early neonatal are deaths within the first week, Late neonatal after the first week before the first month, and Post-neonatal after the first month. In columns 5 and 6, infant mortality cases are split by whether the cause of death is preventable. The number of observations is constant across all columns. Thus, in each case, the dependent variable is zero if the child is alive or if her death belongs to another group, e.g., if it is not an early neonatal death, it could be because the child is still alive or died after the first week of life. In this way, coefficients in columns 2-4 add up to the coefficient in column 1, as coefficients 5 and 6 do.

Panels A and B of Table 2 indicate that most of the effect of the distance on infant mortality comes from neonatal and preventable deaths. Panel A shows that traveling to another municipality for childbirth increases the early neonatal mortality rate by 0.48 points and the late neonatal mortality rate by 0.16 points, representing 62,5% of the effect on infant mortality. Likewise, this effect on the preventable mortality rate is 0.69 points, 66.5% of the effect on infant mortality. In relative terms, traveling has a slightly more significant impact on neonatal deaths. This effect represents an 18% increase in the early mortality rate and a 19% increase in the late neonatal mortality rate. However, it is only a 16% increase in the post-neonatal mortality rate. Panel B results follow similar patterns. Furthermore, if we weigh the elapsed time of neonatal versus post-neonatal deaths, the distance effect on the former is even more salient. Thus, the distance effect is 0.645 points (0.483 + 0.162) during the first month of life and 0.035 points per month (0.387/11) between the second and eleventh month of life, assuming it is linear from the second month onward.

Table 1: Models for Infant Mortality Rate

	Infant Mortality Rate				
	(1)	(2)	(3)	(4)	(5)
Panel A: Travel indicator					
Travel= 1	0.2707***	0.1564***	0.1614***	0.1177*	1.0315***
	(0.0503)	(0.0510)	(0.0510)	(0.0698)	(0.1314)
Observations	10,261,152	9,820,529	9,820,529	9,815,675	9,813,184
R-squared	0.0000	0.0094	0.0094	0.0142	0.0202
Mean Dep Var	6.108	5.997	5.997	5.993	5.992
Mean Exp Var	.373	.375	.375	.376	.375
Panel B: Traveling distance					
Distance (in 10 Km)	0.1635***	0.1013***	0.1013***	0.0840***	0.1124***
	(0.0060)	(0.0061)	(0.0061)	(0.0075)	(0.0154)
Observations	10,261,152	9,820,529	9,820,529	9,815,675	9,813,184
R-squared	0.0001	0.0094	0.0094	0.0142	0.0202
Mean Dep Var	6.108	5.997	5.997	5.993	5.992
Mean Exp Var	1.94	1.948	1.948	1.948	1.946
Panel C: Conditional distance (only among travelers)					
Distance (in 10 Km)	0.2332***	0.1369***	0.1362***	0.1138***	0.1034***
	(0.0078)	(0.0078)	(0.0078)	(0.0095)	(0.0201)
Observations	3,832,337	3,687,168	3,687,168	3,683,224	3,679,786
R-squared	0.0002	0.0127	0.0127	0.0202	0.0362
Mean Dep Var	6.277	6.162	6.162	6.16	6.157
Mean Exp Var	5.196	5.188	5.188	5.186	5.18
Mother & Newborn Controls	No	Yes	Yes	Yes	Yes
Risk Controls	No	No	Yes	Yes	Yes
Hospital-year FE	No	No	No	Yes	Yes
Municipality-year FE	No	No	No	No	Yes

This table reports coefficients on several infant mortality rate measures, estimating equation (1). Outcome variables: general infant mortality. Panel A uses dummy indicating if the mother traveled for childbirth (=1) or not (=0) as a regressor. Panel B uses the traveled distance in 10 kilometers units, and Panel C uses only travelers' distances (i.e., eliminating zeros). Mother and newborn controls are mother's second or more childbirth, 1-3, 4-7, 8-12, and more than 12 years of mother's education, mother is white, single mother, 1-3, 4-7, and seven or more prenatal consults, APGAR 1, birthweight, and birthweight squared. Risk controls are newborn with abnormalities, prematurity, mother's age and age squared, and multiple pregnancy. Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

In Panel C, the concentration of the distance effect on neonatal and preventable deaths reduces moderately. Comparing panels B and C, we can see that ten additional kilometers increase the early neonatal mortality rate by 0.051 points for the whole sample but only by 0.035 for the travelers' sample. Similarly, this effect on the preventable mortality rate reduces from 0.054 to 0.031 points if we restrict the sample to travelers only. Despite its reduction, the effect of the distance on neonatal (preventable) mortality still represents 34% (30%) of the effect on infant mortality.

Table 2: Models for Infant Mortality Measures

	(1)	(2)	(3)	(4)	(5)	(6)
Outcomes	Infant	Early Neonatal	Late Neonatal	Post-neonatal	Preventable	Non-preventable
			Panel A: Travel indicator			
Travel= 1	1.0315***	0.4827***	0.1621***	0.3867***	0.6857***	0.3458***
	(0.1314)	(0.0882)	(0.0498)	(0.0845)	(0.1124)	(0.0686)
Observations	9,813,184	9,813,184	9,813,184	9,813,184	9,813,184	9,813,184
R-squared	0.0202	0.0214	0.0111	0.0106	0.0191	0.0120
Mean Dep Var	5.992	2.696	.848	2.448	4.377	1.615
Mean Exp Var	.375	.375	.375	.375	.375	.375
			Panel B: Traveling distance			
Distance (in 10 Km)	0.1124***	0.0507***	0.0179***	0.0438***	0.0536***	0.0588***
	(0.0154)	(0.0103)	(0.0058)	(0.0099)	(0.0132)	(0.0080)
Observations	9,813,184	9,813,184	9,813,184	9,813,184	9,813,184	9,813,184
R-squared	0.0202	0.0214	0.0111	0.0106	0.0191	0.0120
Mean Dep Var	5.992	2.696	.848	2.448	4.377	1.615
Mean Exp Var	1.946	1.946	1.946	1.946	1.946	1.946
			Panel C: Conditional distance (only among travelers)			
Distance (in 10 Km)	0.1034***	0.0353***	0.0195**	0.0486***	0.0309*	0.0726***
	(0.0201)	(0.0136)	(0.0078)	(0.0127)	(0.0170)	(0.0108)
Observations	3,679,786	3,679,786	3,679,786	3,679,786	3,679,786	3,679,786
R-squared	0.0362	0.0366	0.0255	0.0231	0.0341	0.0267
Mean Dep Var	6.157	2.803	.925	2.429	4.386	1.771
Mean Exp Var	5.18	5.18	5.18	5.18	5.18	5.18
Mother & Newborn Controls	Yes	Yes	Yes	Yes	Yes	Yes
Risk Controls	Yes	Yes	Yes	Yes	Yes	Yes
Hospital-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Municipality-year FE	Yes	Yes	Yes	Yes	Yes	Yes

This table reports coefficients on several infant mortality rate measures, estimating equation (1). Outcome variables: general infant mortality. Panel A uses dummy indicating if the mother traveled for childbirth (=1) or not (=0) as a regressor. Panel B uses the traveled distance in 10 kilometers units, and Panel C uses only travelers' distances (i.e., eliminating zeros). Mother, newborn and risk controls are detailed in Table 1. Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

6.2 High-risk pregnancies

This section focuses on the sample of high-risk pregnancies. Instead of estimating the effect of the distance mothers traveled to give birth, the section focuses on the effect of living farther from health facilities that provide different levels of perinatal care. Table 3 shows the effect of distances to the closest facilities providing level I, II, or III care on infant mortality under different specifications. Distances are standardized to make them comparable. Column 1 of Table 3 shows that, without controls, living one standard deviation (s.d.) farther from level-I facilities increases the infant mortality rate by 1.05 points, whereas living one s.d. farther from level-III facilities reduces it by 1.3 points; the level-II effect lies in the middle. Once we control for mother and newborn characteristics and pregnancy risks in columns 2 and 3, the sign of level-I and level-III effects reverses, the level-II effect increases, and the level-I effect becomes statistically non-significant.

Section 4 showed that level-I facilities are much closer and more equally distributed than level-II and level-III facilities. The latter are primarily on the east coast of Brazil, the country's wealthiest region, most likely the residence of mothers and newborns with better socioeconomic backgrounds. Thus, we expect a negative partial correlation between level-III and level-II facilities and mother and baby background and a positive partial correlation between these last variables and level-I facilities[13]. These correlations explain why level-III and level-II effects become more positive after introducing mother and newborn controls and risk factors, and level-I effects go to zero.

The last column of Table 3, our preferred specification, introduces municipal controls, most of which measure municipal poverty[14]. Consistent with columns 2 and 3, the level-II and level-III effects reduce after the inclusion of these variables, but they remain statistically significant. These results are consistent with the positive effect of access to technology on high-risk newborns found in previous studies (e.g. Lorch et al. (2012); Barfield et al. (2012)). In our case, one s.d. increase in the distance to the closest level-II and level-III facilities raises the infant mortality rate by 0.937 and 0.399 points, respectively. Given the access to all levels of care, the level-II effect being higher than the level-III effect implies that being closer to intermediate neonatal care and surgical-obstetric care would reduce infant mortality more than the proximity to critical care.

[13]People with worse backgrounds would travel more to access better medical technology, as they already do on average. Still, given that level-I facilities are relatively close to anywhere, correlation for this level could be non-significant.

[14]Full list can be found on table notes.

Table 3: Infant Mortality Models of Distances to the Closest Levels of Care

	(1)	(2)	(3)	(4)
Level I	1.0549***	-0.0501	-0.0412	-0.1730
	(0.1790)	(0.1580)	(0.1573)	(0.1604)
Level II	0.4169*	1.6125***	1.7033***	0.9365***
	(0.2254)	(0.1893)	(0.1878)	(0.2029)
Level III	-1.3091***	1.0285***	1.0178***	0.3988**
	(0.2088)	(0.1911)	(0.1942)	(0.1742)
Observations	3,499,120	3,361,184	3,361,184	3,360,981
R-squared	0.0002	0.1972	0.2383	0.2385
Mean Dep Var	28.674	28.447	28.447	28.446
Year FE	Yes	Yes	Yes	Yes
Mother & Newborn Control	No	Yes	Yes	Yes
Risk Controls	No	No	Yes	Yes
Municipal Controls	No	No	No	Yes

This table estimates the effects of the distances to the closest facilities providing level I, II, or III perinatal care on infant mortality using equation (2). Distances are standardized by their mean and standard deviation. The infant mortality rate is expressed in deaths per 1000 live births. Thus, level-of-care coefficients should be interpreted as the change in the infant mortality rate of one standard deviation increase in the distance. Mother, newborn and risk controls are detailed in Table 1. Municipal controls are life expectancy at birth, fertility rate, dependency rate, aging rate, expected years of education at age 18, illiteracy rate at age 25 or older, child population rate in households with incomplete fundamental education, Gini index, extreme child poverty rate, per capita income, formal occupation rate, population rate living in overcrowded households, population rate in households with inadequate walls, population rate with garbage collection services, population rate with electric power, population rate with bathroom and water, population size (in logs), and urbanization rate. Clustered-robust standard errors are in parentheses. The cluster is at the municipal level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 4 shows the effect of the distance to the different levels of care on the same infant mortality measures of Table 2. The results correspond to the model that includes all control variables (column 4 of Table 3). Column 2 shows that the effect of the distance to the closest municipality with level-III facilities on infant mortality is concentrated in the early neonatal period. The level-III effect on early neonatal mortality is 0.52 points per one s.d., 1.3 times higher than the effect on infant mortality. On the other hand, the level-III effects on late neonatal and post-neonatal mortality rates are statistically not different from zero (columns 3 and 4). Similarly, level-II effects also concentrate on the early neonatal period; the effect on late neonatal mortality is significant but minor (20% of the effect on infant mortality), and the effect on post-neonatal mortality is not statistically significant. These results also correlate with what we find in Table 2 for the low-risk sample.

When separating infant mortality cases by the preventability of their cause of death (columns 5 and 6 of Table 4), we observe that the effect of the distance to the closest level-II facility on infant mortality is concentrated on preventable causes. However, this result does not happen with level-III care. The level-II effect on preventable mortality rate is 77% of the effect on infant mortality rate (0.724/0.936). In contrast, the level-III effect on preventable mortality rate is 55% of the effect on infant mortality rate, but it is not statistically significant (0.221/0.399). Though not too precise, as in low-risk pregnancies (Table 2), the increase in infant mortality rate associated with living farther away from municipalities with specialized medical technology (levels II or III) is primarily coming from preventable deaths.

We perform several robustness exercises to determine the consistency of our results. First, we estimate alternative models where we introduce the levels of care separately, disaggregated by production inputs: infrastructure and equipment. In addition, we include a human resources classification that is available only after 2012. The models use all control variables and are estimated for the high-risk and low-risk samples. The orange point estimates and confidence intervals depicted in Figure 8 show the high-risk sample results. Level-II and level-III effects independently have explanatory power and reproduce the pattern presented in Tables 3 and 4: Their effect is concentrated on early neonatal and preventable deaths (See first three lines of panels a,b, and e versus the other panels of Figure 8).

Observing the infrastructure and equipment components of the levels of care separately, we find that the effect of the distance to the closest level-II infrastructure and level-III equipment on the infant, early neonatal, and preventable mortality rates is systematically positive and statistically significant across all specifications. This pattern is consistent with the aggregated results. However, the effects of the distance to level-II equipment and level-III infrastructure are only sometimes significant and contribute to infant mortality rates only when combined with the other inputs. Lastly, we find that the classification of human resources by level of care also reproduces the same pattern of effects on infant and early neonatal mortality of the aggregated classification. This finding reflects the complementarity of the production of health services.

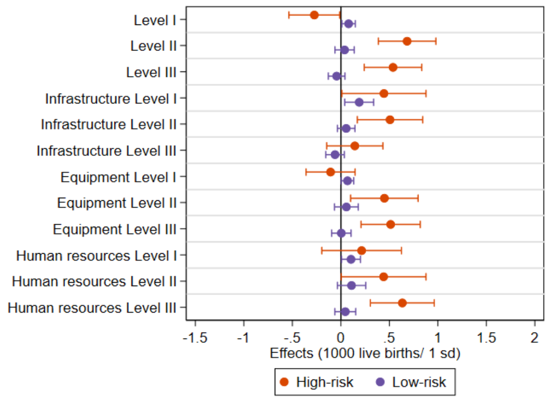
Table 4: Distance to the Closest Levels of Care Models for Infant Mortality Measures

VARIABLES	(1) Infant	(2) Early Neonatal	(3) Late Neonatal	(4) Post-neonatal	(5) Preventable	(6) Non-preventable
Level I	-0.1730	-0.3116**	0.1195**	0.0190	-0.2688**	0.0957
	(0.1604)	(0.1265)	(0.0523)	(0.0543)	(0.1336)	(0.0627)
Level II	0.9365***	0.6855***	0.1421**	0.1089	0.7238***	0.2127**
	(0.2029)	(0.1770)	(0.0641)	(0.0765)	(0.1792)	(0.0931)
Level III	0.3988**	0.5223***	-0.0410	-0.0826	0.2210	0.1778**
	(0.1742)	(0.1355)	(0.0508)	(0.0597)	(0.1474)	(0.0702)
Observations	3,360,981	3,360,981	3,360,981	3,360,981	3,360,981	3,360,981
R-squared	0.2385	0.2149	0.0334	0.0146	0.2290	0.0767
Mean Dep Var	28.446	17.447	4.811	6.188	21.262	7.184
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Mother & Newborn Controls	Yes	Yes	Yes	Yes	Yes	Yes
Risk Controls	Yes	Yes	Yes	Yes	Yes	Yes
Municipal Controls	Yes	Yes	Yes	Yes	Yes	Yes

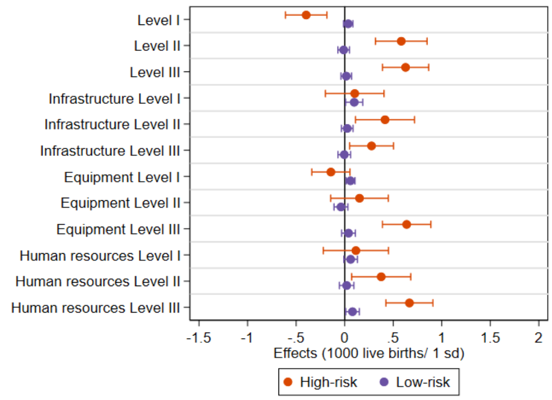
This table estimates the effect of the minimum distance to levels of care on different measures of infant mortality using equation (2). Distances are standardized by the mean and standard deviation of the sample. Infant mortality is expressed in deaths per 1000 live births. Thus, level-of-care coefficients should be interpreted as the change in the infant mortality rate of one standard deviation increase in the minimum distance. Control variables are detailed in Table 3. Clustered-robust standard errors are in parentheses. The cluster is at the municipal level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

The low-risk-sample estimates are helpful as a placebo-like test. The levels of care add a layer to our analysis because instead of focusing on access to any medical attention, the distance to facilities with different levels of care reflects the access to specialized medical technology. Low-risk pregnancies would require specialized medical attention less frequently than high-risk pregnancies. Hence, we expect lower level-II and level-III effects for low-risk pregnancies. Our results confirm those hypotheses: As the purple point estimates and confidence intervals of Figure 8 show, all the effects of the distance to the closest levels of care on the different measures of infant mortality are close to zero and the majority are statistically not significant.

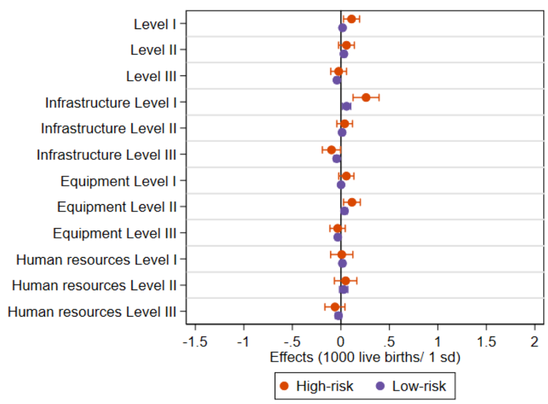
Figure 8: Effects of the Distance to the Closest Facility on Infant Mortality Measures by Pregnancy Risk



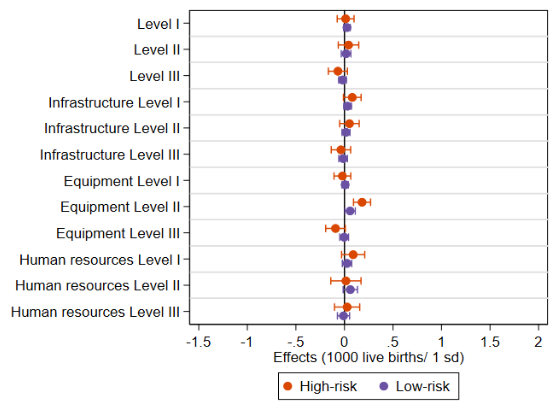
(a) General



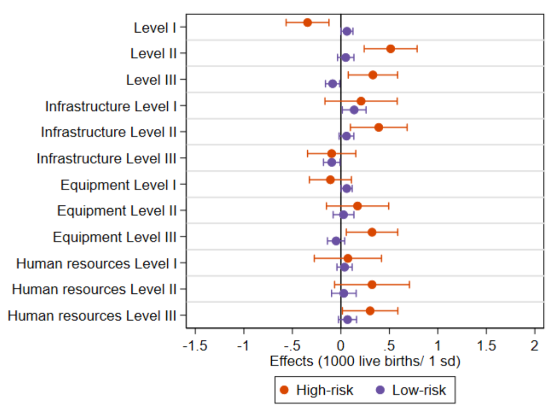
(b) Early Neonatal



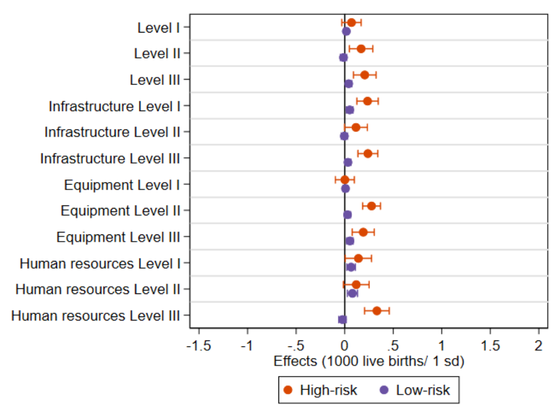
(c) Late Neonatal



(d) Post-neonatal



(e) Preventable



(f) Non-preventable

Note: Figure shows coefficients of infant mortality measures (Panels a-f) regressed individually on minimum distances to index components by level of care (y-axis list) and control variables. Control variables are detailed in Table 3. Magnitudes are marked on x-axis with 90% confidence interval. Standard errors are robust and clustered at the municipal level. Orange dots are high-risk pregnancies and purple belong to low-risk sample.

Finally, we estimate the effect of the distance to the closest infrastructure items on different infant mortality measures. As Figure 9 shows, the items are ordered from the most to the least complex, i.e., from level-III to level-I items. Regression models are estimated for low-risk and high-risk samples using the complete set of controls. The results are consistent with the level-of-care estimates: significant effects come from the high-risk pregnancy group and early neonatal and preventable deaths.

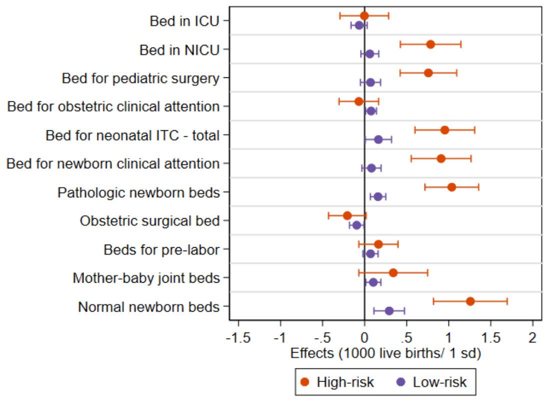
We can also identify some critical items for which we observe significant effects. For example, regarding infrastructure, the level-of-care effects mainly reflect the availability of beds for neonatal intermediate and critical care (ITC and NICU beds). Between those two types of beds, the former has a higher effect on preventable deaths, while the latter has a higher effect on early neonatal deaths. Furthermore, being farther from beds for inpatient obstetric care and normal deliveries, particularly the frequently-available mother-baby joint beds, does not affect infant mortality of high-risk pregnancies[15].

7 Conclusion

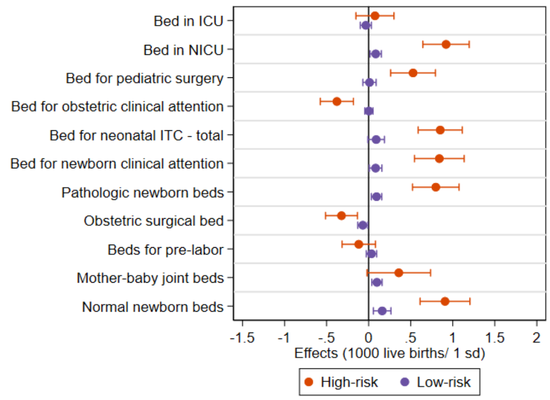
This paper analyses the effect of the distance mothers travel to give birth on infant mortality in Brazil. After controlling for several socioeconomic and risk factors, we find that traveled distance and infant mortality remain positively correlated under different empirical strategies. Among low-risk pregnancies, traveling to another municipality could increase infant mortality by 17%, and each additional ten kilometers of journey raise the infant mortality rate by 0.1 points per 1000 live births. For high-risk pregnancies, the distance to any facility is less relevant than the (minimum) distance to facilities with specialized medical technology. Thus, living one s.d. farther away from level-II and level-III facilities increases the infant mortality rate by 0.94 and 0.4 points, respectively. Consistent with the literature on the importance of access to medical technology at birth, we systematically find that the effect of distance on infant mortality is concentrated on early neonatal and preventable deaths.

[15]We do not disaggregate equipment and human resources by item because they are not specific to obstetric and neonatal care. Therefore, it would be cumbersome to attribute the effect on infant mortality to each item independently.

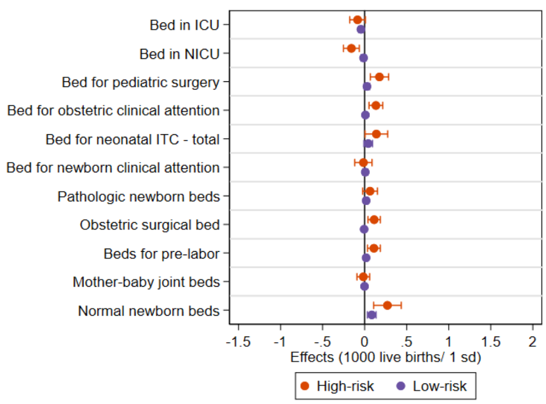
Figure 9: Effects of the Distance to the Closest Infrastructure on Infant Mortality Measures by Pregnancy Risk



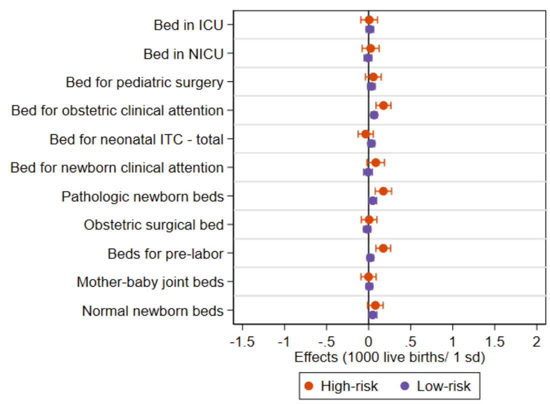
(a) General



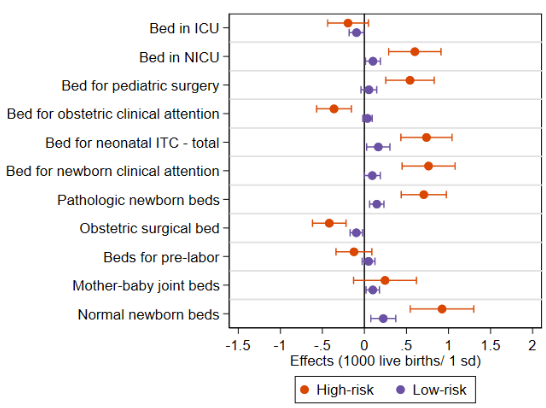
(b) Early Neonatal



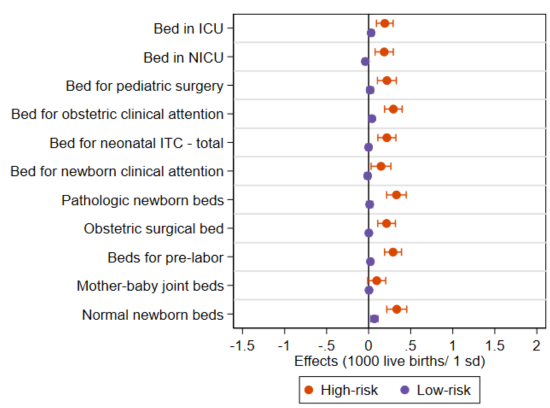
(c) Late Neonatal



(d) Post-neonatal



(e) Preventable



(f) Non-preventable

Note: Figure shows coefficients of infant mortality measures (Panels a-f) regressed individually on minimum distances to infrastructure inputs (y-axis list from most complex on top to least complex at bottom) and control variables. Control variables are detailed in Table 3. Magnitudes are marked on x-axis with 90% confidence interval. Standard errors are robust and clustered at the municipal level. Orange dots are high-risk pregnancies and purple belong to low-risk sample.

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Appendices

A Additional results

Table A.1: Facility characteristics by perinatal level of care (2015)

	Level 0		Level I		Level II		Level III	
	%	N	%	N	%	N	%	N
Type of facility:								
Hospital	57.6	186	83.2	1409	82.9	243	95.5	147
Normal Delivery Center	0.9	3	0.2	4	0	0	0	0
Other hospitals	1.9	6	3.7	63	15.4	45	4.5	7
Emergency units	3.1	10	0.4	7	1.4	4	0	0
Other facilities	36.5	118	12.5	211	0.3	1	0	0
Type of care:								
Outpatient	10.9	35	0.4	6	0	0	0	0
Inpatient	89.1	287	99.6	1673	100	292	100	154
Complexity of inpatient care:								
Low	12.5	36	8.2	138	1.4	4	0	0
Medium	71.1	204	66.3	1109	27.4	80	2.6	4
Medium + Diagnostics	9.4	27	15.2	255	29.5	86	7.1	11
High	7.0	20	10.2	171	41.8	122	90.3	139
Patient volume (births):								
$\leq$ 75	57.9	187	31.6	536	4.4	13	5.8	9
75-209	22.9	74	28.4	481	7.8	23	0.6	1
209-656	14.2	46	23.2	393	19.5	57	7.1	11
>656	5.0	16	16.8	284	68.3	200	86.4	133
Very preterm births (count)								
Below median	76.2	246	60.2	1019	17.1	50	6.5	10
3rd quartile	20.1	65	25.0	423	22.2	65	3.9	6
4th quartile	3.7	12	14.9	252	60.8	178	89.6	138
Very low weight births (count)								
1st quartile	66.9	216	50.6	858	13.0	38	5.2	8
2nd quartile	17.0	55	20.2	342	10.2	30	1.3	2
3rd quartile	12.7	41	16.8	285	15.0	44	0.6	1
4th quartile	3.4	11	12.3	209	61.8	181	92.9	143
Observations	323		1694		293		154	

Notes: Level I: A facility capable of assisting low-risk births. Level II: A facility capable of assisting high-risk births requiring obstetric surgical interventions and intermediate neonatal care. Level III: A facility capable of assisting high-risk births requiring obstetric or neonatal critical care. Level 0: Residual level, not satisfying any of the criteria above.

Complexity of inpatient care is the MOH's facility classification. Low-complexity facilities perform basic and first referral outpatient procedures, deliveries, pediatric hospitalizations, minor clinician and surgical procedures. Medium-complexity facilities perform first and second referral outpatient procedures and medium-complexity hospital procedures. All specialized hospitals belong in this category. Medium+Diagnostics facilities provide high complexity outpatient diagnostic services in addition to medium-complexity facilities' procedures. High-complexity facilities focus on inpatient and outpatient highly complex procedures (Brazil. Ministerio da Saúde, 2022). Very preterm births are those with 22 weeks or less of gestational age. Very low birth weights are those with 1500 grams or less of weight at birth.

Source: Pinho Neto et al. (2023)