Effects of distances on newborn outcomes in Brazil

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Abstract

Travel distances can affect the delivery outcomes of pregnant women. Using detailed national data, this paper identifies the effect of the distance to the place of delivery on infant mortality between 2006 and 2017 in Brazil. The paper follows an empirical strategy developed in two stages. First, we estimate the correlation between the infant mortality and the distance traveled by pregnant women using a linear regression model. We find statistically significant and positive effects that are robust to the introduction of multiple fixed effects, socioeconomic and risk factors. In the most saturated model, traveling 10 additional kilometers to give birth increases the infant mortality in 1.93 deaths per 1000 live births. Second, we estimate the effect of the proximity to facilities with different levels of care, infrastructure, equipment and human resources on infant mortality. As the distance to the closest facility or health input do not necessarily coincide with the effective journey a women made for birth, these estimates have lower endogeneity bias. Consistent with the literature, we find that one standard deviation increase in the minimum distance to Level-III facilities increases the infant mortality by 0.5 deaths per 1000 live births among high-risk pregnancies. Consistently, we find similar effects on infant mortality of the minimum distance to Neonatal Intensive Care Unit (NICU), pathological newborn and intermediate care unit beds, and medical specialists.

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 displacement leads to a reduction in preventive care and care is delayed in an emergency 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], if they jeopardize the informal care provided by family members, or if they 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 where the pregnancy presents some risk and requires specific care or equipment during delivery or postpartum. However, the causal relationship is of difficult identification, as risk and hospital quality are likely to be correlated with distances traveled and maternal-child health outcomes. Identifying these effects is thus 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 location of birth on infant mortality in 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, Instituto de Comunicação e Informação Científica e Tecnológica em Saúde), 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).

Based on this information, we describe the evolution of travel distances to the municipality of birth, identifying that throughout the decade more women left their municipalities of residence to deliver their babies. Further, the average travel distance also increased during this period. The distance to municipalities with delivery facilities is associated with several socioeconomic and risk variables, but also with lower survival rates. We also depict the geographic distribution of health facilities, qualified by the level of perinatal care they offer, showing the striking geographic inequality in the access to technologically dense services, which are particularly relevant to save babies at risk.

Then, we conduct a linear regression analysis to measure the effect of the traveled distance on infant mortality. Although we cannot claim we have identified a causal effect, we show that our results are robust to the inclusion of several socioeconomic characteristics and fixed effects. In the most saturated model, traveling 10 additional kilometers to give

[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)

birth increases the infant mortality in 1.93 deaths per 1000 live births.

The limitation of the previous estimates is that the decision to travel and the displaced distance are endogenous. To overcome this problem, we use the minimum distance to a certain health facility instead of the effective traveled distance, and estimate the effect of this variable on infant mortality. Results are statistically significant for the distance to Level-III facilities and of higher magnitude for early neonatal and preventable deaths, particularly among high-risk pregnancies. One standard deviation increase in the distance to Level-III facilities increases the infant mortality rate in at least 0.5 deaths per 1000 live births for the group of high-risk pregnancies. Consistently, we find similar effects on infant mortality of the minimum distance to Neonatal Intensive Care Unit (NICU), pathological newborn, intermediate care unit beds, and medical specialists.

The paper develops as follows. This section contained the introduction. Section 2 summarizes the literature of the effect of distances on mother-child health outcomes. Section 3 describes the data, and Section the institutional setting and background. Section 5 details the empirical strategy for the identification of the effect of the 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). Furthermore, care during childbirth is a health procedure that must necessarily occur in person, so technological advances in this area are restricted to the techniques implemented and not to the reduction of the pregnant woman's need for mobility.

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).

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 further away from these clinics. 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. The results support the hypothesis that distance is an important obstacle in the decision to perform certain health procedures.

In the context of maternal and child health, evidence shows that 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. 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.

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, record the highest rates of distances to travel and travel time (Weiss et al., 2020). Even in a context of local accessibility, such as the intramunicipal, spatial segregation is present, given that high-complexity health facilities tend to be more concentrated in central regions of cities so that the peripheral population has lower levels of accessibility than the older population. rich (Pereira et al., 2020).

Displacements are also present in childbirth: almost a third [2] of births in Brazil occur in municipalities other than the mother's residence (Pinho Neto et al., 2022). 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. While infant mortality has declined, these same shifting trends hold for the remaining infant mortality (Pinho Neto et al., 2022). Even the alternative to facing long distances for childbirth is not a good one: in developed countries, which experience increasing rates of home birth, this type of birth has the highest neonatal mortality rates (Daysal et al., 2015).

It's not an easy-to-solve problem. The construction of clinics, hospitals, and health units is expensive, and requires hiring and the presence of trained personnel and specialized health equipment, in addition to its maintenance. However, through data processing, it is possible to identify regional problems and the most seriously affected public, in order to properly direct public resources to the most vulnerable population and optimize the spatial distribution of health services.

Considering Brazil's socioeconomic and regional inequalities, it is likely that women who travel for childbirth do so because they are in a risky pregnancy situation [3] or because they do not have access to adequate health services and equipment in their hometowns.[4]

This article is part of the literature that studies the effects of distances traveled to perform childbirth on maternal and infant health, especially neonatal mortality. Evidence of this effect in the literature is still scarce, possibly due to the difficulties of obtaining identified geospatial data, and the endogeneity problem raised by the causal identification of this relationship. As distances traveled and birth and maternal health outcomes are likely to be correlated with pregnancy risk and hospital quality, these factors need to be purged to correctly identify the effect of distances, eliminating selection bias.

[2] Pinho Neto et al. (2022) show that 31% of births in Brazil in 2017 took place outside the mother's municipality of residence.

[3] NOTE: I did not find any results in this line in policy papers by Neto and team. However, in Pinho Neto et al. (2022), they mention that the article will look at geographic access at birth by type of labor and risk level. If you have data along these lines, this might be a good place to include this evidence.

[4] NOTE: Idem.

Despite the challenges, it is essential to investigate the extent to which these distances negatively affect birth and maternal health, and to understand how they exacerbate regional inequalities. Estimating the effects, identifying in which health outcomes they are significant, calculating their magnitudes, and detecting their heterogeneities is, therefore, essential to address the problem where it is most serious and thus foster the debate of evidence-based public policies with formulators. [5]

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, Instituto de Comunicação e Informação Científica e Tecnológica em Saúde), that gathers information from DATASUS (Health Ministry database). First, the Brazilian Information System of Live Births (Sistema de Informações sobre Nascidos Vivos - SINASC)[6] records every woman accessing perinatal services in Brazil with complementary description of socioeconomic variables and medical conditions.

Combined to this, the infant death register, 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 displacement (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 34 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

[5]NOTE: This is where the research questions are inserted. I put in a somewhat loose/generalist paragraph, just to make it clear. I left it that way because I don't know exactly what are the research questions and to what heterogeneities you're looking at.

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

public, private or mixed (Brazil. Ministerio da Saúde, 2022a). We concentrate our attention on facilities that deliver at least one baby per year, 50 births at least one year throughout the decade, and provide services in the public health system, the SUS system (Sistema Único de Saúde in Portuguese). [7] After applying these filters, we remain with a panel that contains 3360 health facilities; approximately, 2500 facilities per year, with 1793 complete cases (53.4%), 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 MoH requirements, we define levels based on three components: infrastructure, equipment and 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. If it did not meet Level I criteria, we assigned a *Level 0* category. These facilities held a delivery even

[7] 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.

though proper conditions were unavailable. 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. (2022) for more details).

Following this procedure, we crossed the newly-designed classification to the original one in CNES dataset - regarding many hospital services -, 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)[8]. Literature has established a positive relationship between these variables and degree of specialization. (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.

3.2 Geographic access 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 displacements, rather than a simple displaced or did not displace comparison. This procedures takes geographic coordinates (latitude and longitude) of each municipality's downtown neighborhood and runs package *OSM* from *OpenStreetMap* in R software, returning kilometers of displacement 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 which 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.[9]

[8]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.

[9]When calculating averages which aggregate in broader geographic levels, we opted to weight by the count

4 Institutional and Background

This section describes the accessibility to health services and its relation to infant mortality from two perspectives: demand and supply. In the former case, we describe the distance mothers travel to give birth and how it is correlated with their socioeconomic background and the mortality rate. In the latter case, we briefly describe the organization of the Unified Health System in Brazil. Then, using a classification of levels of perinatal care, we show the geographic distribution and access to health facilities with different qualifications.

4.1 Institutional

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).

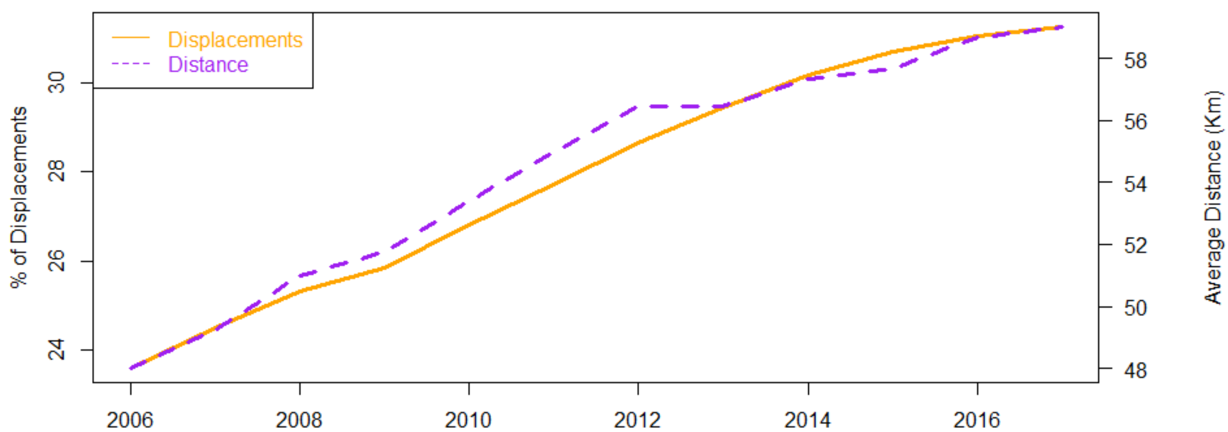
The regionalization of health services started in 2000. The health services were organized in networks that surpassed municipal limits. A health network is an organization of health services and actions of different technological densities, integrated by technical support, logistics, and management systems, 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) (ref). 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 (Ministério da Saúde., 2010).

of births of hosting municipality.

4.2 Access to Health Facilities for Birth in Brazil

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

Figure 1: Share of displacements and conditional displaced distance

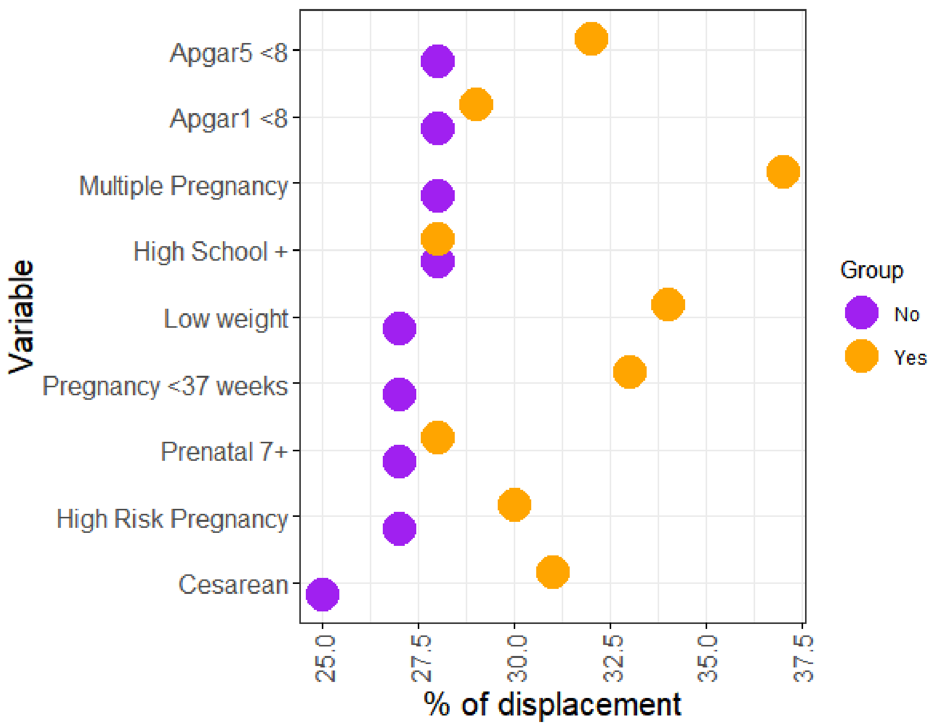


Note: Figure shows share of women who displaced (LHS - in %) and the average distance conditional on displacing by the same group (RHS - in kilometers) at the national level ranging years 2006 to 2017.
Source: Pinho Neto et al. (2022)

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 displace more than their low-risk counterparts. Figure 2 shows that the fraction of women that traveled for birth 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 displacing 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

Figure 2: Individual factors and displacement

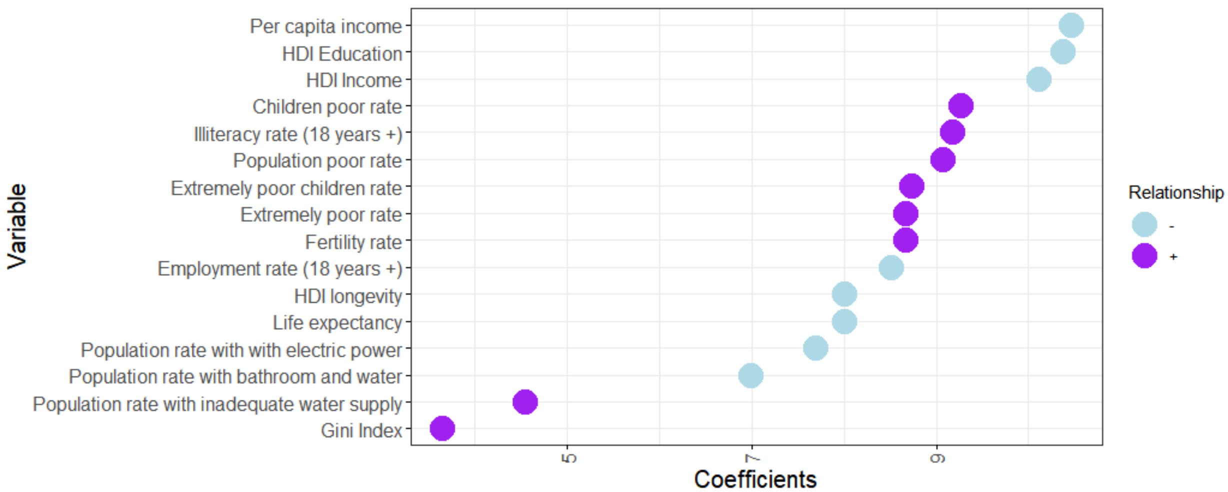


Note: Figure shows the share of displacement (x-axis) by the presence of individual factor (y-axis, Yes in yellow and No in purple).
Source: Pinho Neto et al. (2022)

deviation. Each dot represents a coefficient; blue dots indicate negative effects and purple dots positive effects. The largest coefficient is per capita income, followed by 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, geography is also associated with the distance mothers travel to give birth. 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 displace the largest distances in the country when they travel (Pinho Neto et al., 2022). This geographic pattern changed little between

Figure 3: Socioeconomic factors and distance - Normalized Mean and SD



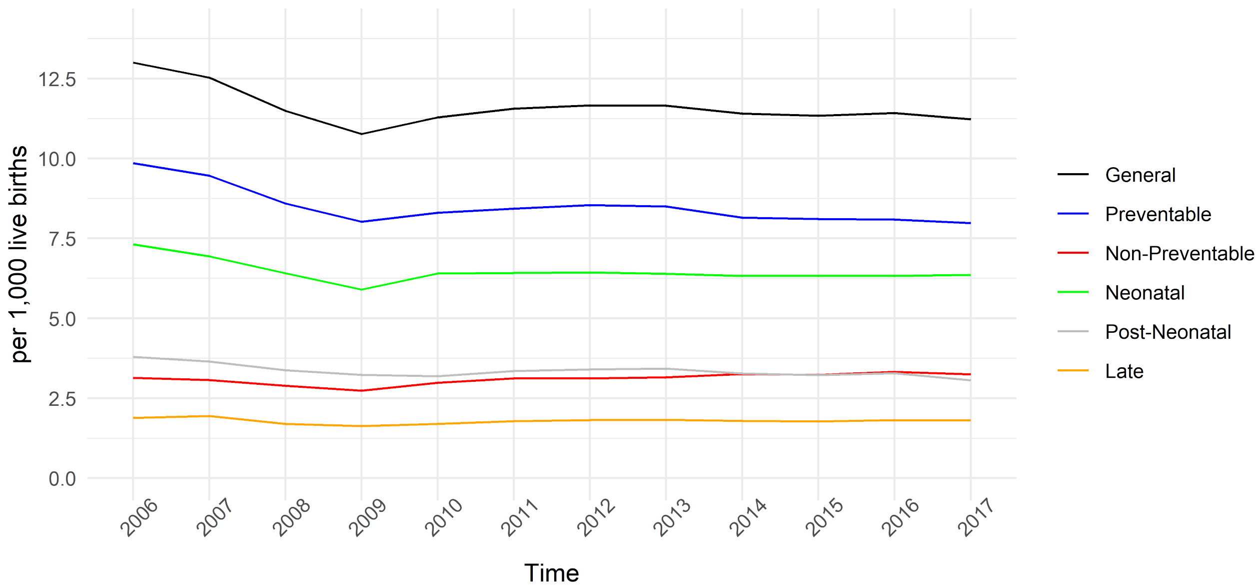
Note: Figure shows estimated coefficient magnitudes (x-axis) of each socioeconomic factor (list on y-axis) regressed separately at the municipal-level against average displaced distance. Colors indicate the signal of correlation: positive in blue and negative in purple.
Source: Pinho Neto et al. (2022)

2006 and 2017 (Pinho Neto et al., 2022).

4.3 Mortality Rates in Brazil

Despite the improvements on child health in the last 30 years, the decrease in infant mortality in Brazil slowed down over the last decade (Leal et al., 2018). The majority of 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 4 shows that the infant mortality reduced only mildly between 2006 and 2017 (black line). Infant mortality is classified by the timing and the cause of death. Trends are similar for all series. The largest components are early neonatal (first week after birth) and preventable deaths, i.e., the green and blue lines. Among preventable causes of death, bacterial sepsis and respiratory distress syndrome were the most frequent (Pinho Neto et al., 2022). These conditions could be avoided by adequate care for women during pregnancy and birth (Leal et al., 2018), thus making access to health services relevant.

Figure 4: Mortality at the national-level by type

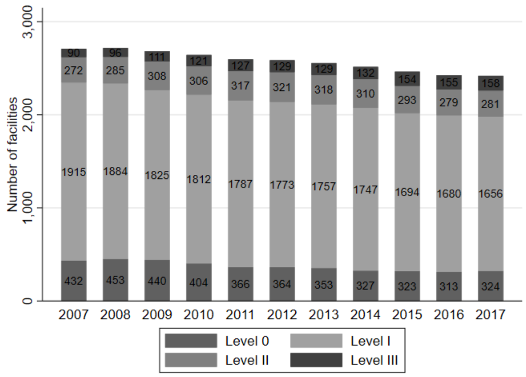


Note: Figure shows time trends for each type of mortality from 2006 to 2017. Black line represents General Mortality and others are decompositions. Preventable (blue) and Non-Preventable (red) refer to cause of death. Neonatal (green), Post-Neonatal (grey) and Late (yellow) refer to timing of death.
Source: Pinho Neto et al. (2022)

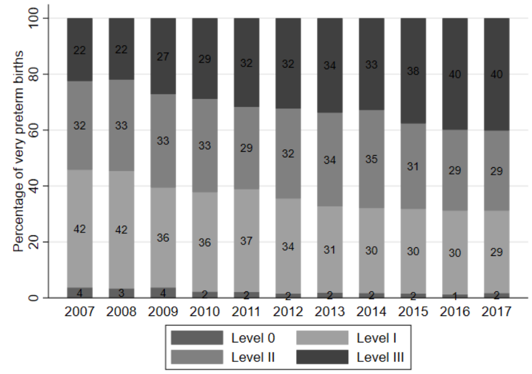
4.4 Availability of Health Infrastructure for Newborns

Figure shows the evolution of the number of facilities by level of perinatal care, as defined in the Data section, between 2007 and 2017. As expected, facilities with the highest technology density - Level-III facilities - are scarcer than the other type of facilities, which is expected because NICUs, ventilators and other high-tech inputs are usually located in high-volume, complex facilities. Yet, the total number of Level-III facilities seem to be insufficient to cover birth attention. As shown in Figure 5b, in 2007, 78% of very preterm births did not happen in Level-III facilities, although they should have. Despite the increase in the number of Level-III facilities during the decade, by 2017, still 60% of the very preterm newborns were born in Level-I or Level-II facilities.

Figure 5: Evolution of facilities and births by perinatal level of care (2007-2017)



(a) Facilities

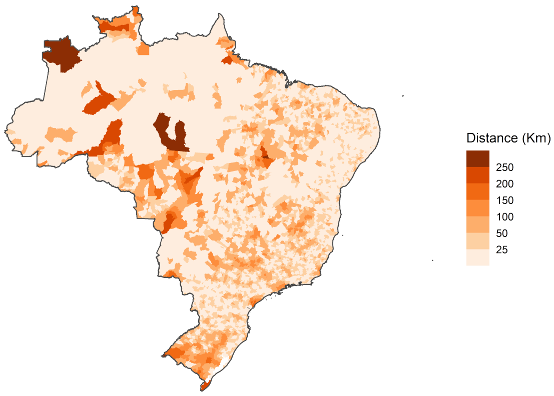


(b) Very preterm births

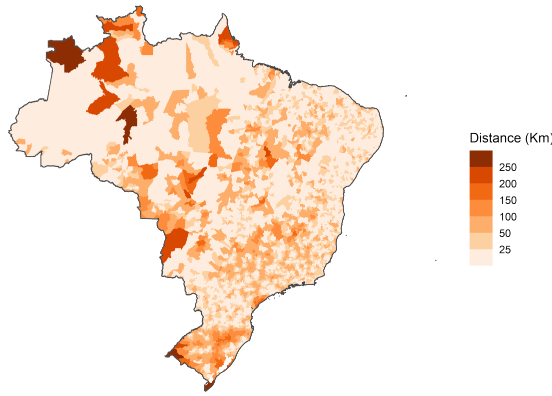
Source: Pinho Neto et al. (2022)

More troublesome is the geographic distribution of Level-III facilities, heavily concentrated in Brazil's northeast and southeast regions. Figure 6 depicts with a color palette the minimum distance of a health facility with 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 - panels c and f - 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 an improvement in the access to Level-III facilities, consistent with the increase in their number between 2007 and 2017 (Figure 5).

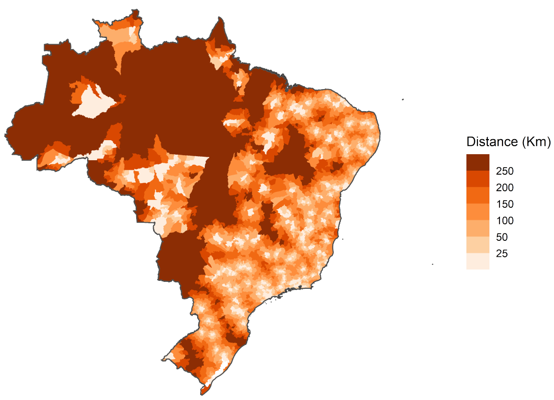
Figure 6: Municipal maps of minimum distances to health facilities by perinatal level of care



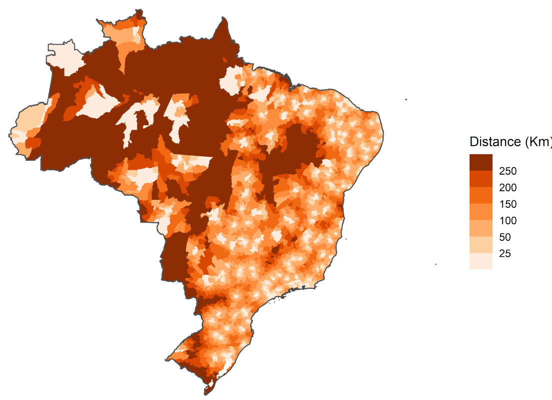
(a) Level I - 2007



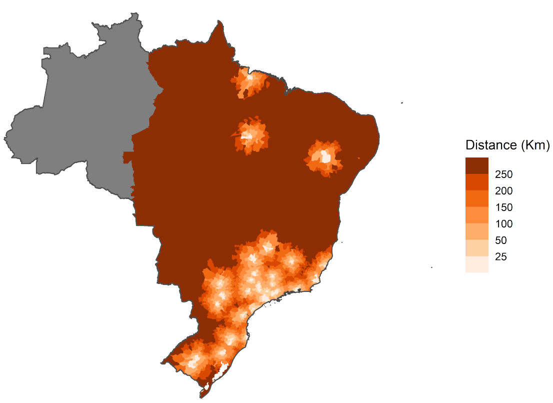
(b) Level I - 2017



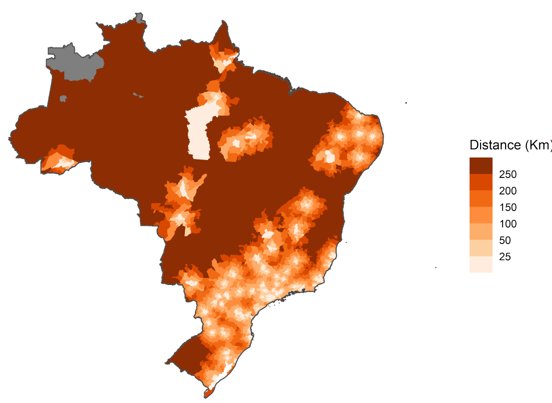
(c) Level II - 2007



(d) Level II - 2017



(e) Level III - 2007



(f) Level III - 2017

Note: Figure shows the shortest traveling distance between one municipality and another containing a facility of a certain level 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.
Source: Pinho Neto et al. (2022)

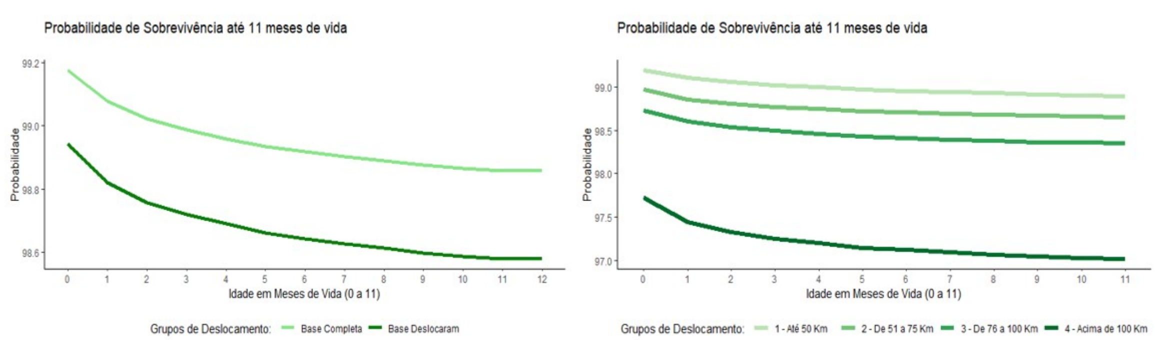
Level-II facilities are more accessible than Level-III facilities. Figure 6 shows that some mothers from the Central-west and North regions live close to Level-II facilities. Level II has obstetric surgical beds and intermediate care units. Thus we can infer that access to this infrastructure is more equitable than access to NICUs or other Level-III infrastructure. Nevertheless, as Level-III facilities, Level-II facilities tend to concentrate in the Southeast and Northeast regions.

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 2017. 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 132 in 2007 to 83.1 Km in 2017. In the latter, the average distance changes from 98.7 to 64.1 Km over the same period (See Pinho Neto et al. (2022) for more details of minimum distances to equipment, infrastructure, and human resources).

5 Empirical strategy

Figure 7 presents suggestive evidence that the distance to health facilities matters for children's survival. Panel a shows that the probability of surviving the first year of life is 0.2 percentage points higher for children with mothers that traveled to give birth. Further, panel b displays different survival curves that change with the distance traveled. Thus, the probability of surviving is close to 2 percentage points higher for children whose mothers traveled 50 Km instead of more than 100 Km.

Figure 7: Survival curves of children under one year of life by distance to place of birth



(a) Displacement vs No Displament

(b) By traveled distance

We are interested in identifying the effect of the distance to delivery facilities on infant mortality. A positive association between these two variables does not imply a causal relationship because observable and unobservable confounders could be sources of bias. First, municipal socioeconomic characteristics, such as living conditions or the distribution of risk factors, could simultaneously affect mortality and distance to health facilities. Second, the distance to facilities increases with the complexity of care. Hospitals receiving the most complex cases are fewer in number and further apart, partly due to the organization of health networks. Consequently, these hospitals would have higher mortality rates even with better quality. Third, mothers and children with risk factors may travel more. In addition, the mother's socioeconomic characteristics affect her decision to travel.

The following model estimates the correlation between infant mortality and distance to the municipality where the delivery facilities is located, controlling for potential confounders.

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

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 observable characteristics of the mother and the birth, and pregnancy risk factors. α_{mt}, ϕ_{ht} are municipality-time, facility-time fixed effect interactions. Municipality and hospital fixed effects control for observable and unobservable trends in the place of residence and hospital characteristics. After including these variables, the remaining correlation between distance to facilities and infant mortality is explained by mother's idiosyncrasy and geographic factors, thus approximating 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, thus isolating the intensive margin of the traveled distance. In each specification, we analyze the robustness of β, which measures the effect of the distance on infant mortality, 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.

Equation (1) does not identify causal effects. The model does not consider unobserved mother and child characteristics and facility's invariant characteristics. The traveled distance is still endogenous as it results from a mother-health personnel decision process involving cost-quality of services trade-offs, mother's preferences and skills, unmeasured risk factors, and health system organization (e.g., referral norms). None of the above is accounted for in equation (1).

Alternatively, we consider the following model.

$$IM_{imrt} = \omega MD_{mrt} + \delta_{rt} + \theta X_{it} + \phi M_m + \epsilon_{imrt}, \tag{2}$$

where MD_{imrt} is the minimum distance between the municipality of residence m and the municipality where a type of facility, infrastructure, equipment, or human resource relevant for mother-child attention is located. MD_{imrt} can be a scalar or a vector of distances. For comparability purposes, all minimum distances are normalized with respect to their means and standard deviations. IM_{imrt} and X_{it} are defined as in equation (1), δ_{rt} are health region-time fixed effects, and M_m are municipal characteristics, such as the HDI, literacy, poverty or access to basic services.

The coefficient of interest is ω, which we interpret as an Intention to Treat (ITT) effect of the proximity to relevant health attention inputs on infant mortality. The minimum distance considered all inter-municipality trajectory combinations within a radius of 2000 Km, selecting the closest facility with a specific characteristic regardless of whether the route is part of the health network referral system or the mother's choice. In this way, the minimum distance is more exogenous than the distance effectively traveled by the mother.

6 Results

In this section we present the results from regressions based on the forementioned equations. First subsection, Traveled Distances, will focus on Equation 1 and related formats, while the following, Minimum distance to health infrastructure, develops on those concerning Equation 2 and its extensions.

6.1 Traveled Distances

Tables 1 and 2 report coefficients regressed against Infant Mortality Rate, varying included explanatory factors by each column. Panel A uses an indicator variable as distance regressor, which equals 1 whether mother displaced to give birth in a different municipality than the one she resides and equals 0 otherwise. Panel B moves to using distance itself, in a 10 kilometers scale, while in Panel C (Table 2), distance is conditional to displacing, i.e. only positive distances, removing zeros for those that did not displace.

Panel A, Column 1, Table 1 shows equation with no controls or fixed effects. By this estimation, displacing is associated with an increase of 3.36 in Infant Mortality. However, as we include mother and newborn controls, such as education, race, marital status, weight at birth and APGAR index, this number falls five-fold: 0.62. This is due to the positive association between having to displace and these characteristics, which also impact mortality. For instance, a low-educated mother probably has to displace and probably her baby has fewer chances to live. Controlling for this allows us to calculate the exact impact of displacing, unrelated to education. Same holds for risk factors, included in column 3, although, once we already included some controls, correlations are not as clear. Point estimate slightly rises to 0.71. Finally, columns 4 and 5 include fixed effects, accounting, respectively for hospital-year and residence-year levels. While the former implies a reduction of coefficient (to 0.54), latter results in an upsurge: displacing is now associated with an increase of 1.93. Hence, mother's origin and living conditions in her municipality plays a huge part in newborn fate.

Since the indicator bundles mothers that displace short and long distances, Panel B uses distance in a 10 kilometers scale. This means coefficients should be interpreted as the increase in mortality probability associated with an additional displacement of 10 kilometers. Column 1 indicates this association is 0.92 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: by our preferred specification, displacing extra 10 kilometers is associated with a mortality rate 0.26 higher.

Lastly, restricting sample to displacers (Panel C, Table 2) changes little compared to previous panel. Remarks are column 3 reduces compared to column 2 and column 5 coefficient does not grow as much as in the other models. Since we are considering only displacers, risk and living conditions correlate to displacing in such a way that, in this group, their inclusion does not affect mortality as in the wider set of births. In fact, these explain displacing so that, starting in column 2, mother and newborn controls already capture effects close enough, while remaining specifications cause finer adjustments to magnitude.

Table 1: Models for Infant Mortality Rate

Panel A: Indicator of displacement (1 = displaced)

Outcome	Infant Mortality Rate				
	(1)	(2)	(3)	(4)	(5)
1 Displaced	3.3679***	0.6240***	0.7118***	0.5456***	1.9341***
	(0.0403)	(0.0383)	(0.0373)	(0.0420)	(0.0793)
Observations	34,947,365	33,686,251	33,686,213	33,577,264	33,577,232
R-squared	0.0002	0.1167	0.1606	0.1653	0.1676
Mean Dep Var	11.563	11.288	11.288	11.241	11.241
Mean Exp Var	.278	.28	.28	.281	.281
Mother & Newborn Controls	No	Yes	Yes	Yes	Yes
Risk Controls	No	No	Yes	Yes	Yes
Hospital-year Fixed Effects	No	No	No	Yes	Yes
Resid. Municipality-year Fixed Effects	No	No	No	No	Yes

Panel B : Displaced distance

Outcome	Infant Mortality Rate				
	(1)	(2)	(3)	(4)	(5)
Distance (in 10 km)	0.9286***	0.1771***	0.1900***	0.1379***	0.2600***
	(0.0049)	(0.0047)	(0.0046)	(0.0049)	(0.0095)
Observations	34,947,365	33,686,251	33,686,213	33,577,264	33,577,232
R-squared	0.0010	0.1168	0.1607	0.1653	0.1676
Mean Dep Var	11.563	11.288	11.288	11.241	11.241
Mean Exp Var	1.4	1.406	1.406	1.409	1.409
Mother & Newborn Controls	No	Yes	Yes	Yes	Yes
Risk Controls	No	No	Yes	Yes	Yes
Hospital-year Fixed Effects	No	No	No	Yes	Yes
Resid. Municipality-year Fixed Effects	No	No	No	No	Yes

This table reports coefficients on several measures of infant mortality rate, estimating equation (1). Outcome variables: general infant mortality. Panel A uses dummy indicating displacement was made (=1) or not (=0) as a regressor. Panel B uses the traveled distance by 10 kilometers and Panel C uses only displacers' distances (i.e. eliminating zeros). Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 2: Models for Infant Mortality Rate - Cont'd

Panel C : Conditional displaced distance (only among displacers)

Outcome	Infant Mortality Rate				
	(1)	(2)	(3)	(4)	(5)
Distance (in 10 km)	1.0856***	0.1814***	0.1780***	0.1455***	0.1683***
	(0.0068)	(0.0065)	(0.0064)	(0.0075)	(0.0141)
Observations	9,724,880	9,441,239	9,441,233	9,427,432	9,427,292
R-squared	0.0026	0.1326	0.1827	0.1894	0.1971
Mean Dep Var	13.993	13.799	13.799	13.773	13.773
Mean Exp Var	5.031	5.017	5.017	5.014	5.013
Mother & Newborn Controls	No	Yes	Yes	Yes	Yes
Risk Controls	No	No	Yes	Yes	Yes
Hospital-year Fixed Effects	No	No	No	Yes	Yes
Resid. Municipality-year Fixed Effects	No	No	No	No	Yes

This table reports coefficients on several measures of infant mortality rate, estimating equation (1). Outcome variables: general infant mortality. Panel A uses dummy indicating displacement was made (=1) or not (=0) as a regressor. Panel B uses the travelled distance by 10 kilometers and Panel C uses only displacers' distances (i.e. eliminating zeros). Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Tables 3 and 4 are structured as Tables 1 and 2, and panels correspond to which explanatory variable we focus. In the following tables, each column is a type of mortality measure. Column 1 is General mortality and replicates column 5 from Tables 1 and 2, our preferred specification. Others keep the same regressors as controls and fixed effects. Columns 2-4 measures regard timing of death: Neonatal are deaths within the first week, Late after first week within the first month and Post-Neonatal after first month within first year. Columns 5 and 6 address cause of death, by whether it is preventable or not according to registered CID-10 codes. One must note coefficients 2-4 add up to coefficient in column 1, as coefficients 5 and 6 also do.

Panel A, Table 3 show an association of 0.43 and 0.48 in Early Neonatal and Late Neonatal mortality, while approximately double it for Post-Neonatal rate. Note, however, that, given the mean of dependent variables, such coefficients should be relativized: while .43 is 7% of Neonatal Mortality average (6), 1 is about a third of Post-Neonatal. Along the same line, Preventable and Non-Preventable in columns 5 and 6 have similar coefficients but different means.

Estimates are significantly lower in Panel B, when using distance as regressor. In this case, Non-Preventable Mortality stands out compared to Preventable, with an association of 0.2 point (vis-avis a 0.06 point estimate) by extra 10 kilometers. In terms of timing, Late bridges from Neonatal, although falls behind Post-Neonatal.

Panel C, in Table 4, shows no significant effect in Neonatal (column 2) and Preventable (column 5), continuing a tendency from other panels, when effects concentrate in other measures. Conditional distances does not correlate to mortality in these aspects. In other words, these are only associated when having to displace (i.e. a zero distance compared to positive distances in the larger sample).

Table 3: Measures of Infant Mortality

Panel A: Indicator of displacement (1 = displaced)

Outcome	General	Neonatal	Late	Post-Neonatal	Preventable	Non-Preventable
	(1)	(2)	(3)	(4)	(5)	(6)
1 Displaced	1.9341***	0.4360***	0.4839***	1.0142***	0.9891***	0.9451***
	(0.0793)	(0.0582)	(0.0355)	(0.0471)	(0.0678)	(0.0444)
Observations	33,577,232	33,577,232	33,577,232	33,577,232	33,577,232	33,577,232
R-squared	0.1676	0.1636	0.0307	0.0141	0.1662	0.0542
Mean Dep Var	11.241	6.002	1.921	3.318	8.171	3.07
Mean Exp Var	.281	.281	.281	.281	.281	.281
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes

Panel B : Displaced distance

Outcome	General	Neonatal	Late	Post-Neonatal	Preventable	Non-Preventable
	(1)	(2)	(3)	(4)	(5)	(6)
Distance (in 10 km)	0.2600***	0.0487***	0.0833***	0.1280***	0.0593***	0.2007***
	(0.0095)	(0.0069)	(0.0042)	(0.0056)	(0.0081)	(0.0053)
Observations	33,577,232	33,577,232	33,577,232	33,577,232	33,577,232	33,577,232
R-squared	0.1676	0.1636	0.0307	0.0141	0.1662	0.0542
Mean Dep Var	11.241	6.002	1.921	3.318	8.171	3.07
Mean Exp Var	1.409	1.409	1.409	1.409	1.409	1.409
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes

This table reports coefficients on several measures of infant mortality rate, estimating equation (1). Outcome variables (columns): general infant mortality, early neonatal mortality, late neonatal mortality, post-neonatal mortality, infant mortality by preventable cause and infant mortality by non-preventable cause. Preventable and non-preventable classification uses CID-10 criteria. Panel A uses dummy indicating displacement was made (=1) or not (=0) as a regressor. Panel B uses the travelled distance by 10 kilometers and Panel C uses only displacers' distances (i.e. eliminating zeros). Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 4: Measures of Infant Mortality - Cont'd

Panel C : Conditional displaced distance (only among displacers)

Outcome	General	Neonatal	Late	Post-Neonatal	Preventable	Non-Preventable
	(1)	(2)	(3)	(4)	(5)	(6)
Distance (in 10 km)	0.1683***	0.0044	0.0720***	0.0919***	-0.0045	0.1728***
	(0.0141)	(0.0106)	(0.0066)	(0.0082)	(0.0120)	(0.0081)
Observations	9,427,292	9,427,292	9,427,292	9,427,292	9,427,292	9,427,292
R-squared	0.1971	0.1788	0.0450	0.0258	0.1869	0.0870
Mean Dep Var	13.773	7.508	2.482	3.784	9.814	3.959
Mean Exp Var	5.013	5.013	5.013	5.013	5.013	5.013
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes

This table reports coefficients on several measures of infant mortality rate, estimating equation (1). Outcome variables (columns): general infant mortality, early neonatal mortality, late neonatal mortality, post-neonatal mortality, infant mortality by preventable cause and infant mortality by non-preventable cause. Preventable and non-preventable classification uses CID-10 criteria. Panel A uses dummy indicating displacement was made (=1) or not (=0) as a regressor. Panel B uses the travelled distance by 10 kilometers and Panel C uses only displacers' distances (i.e. eliminating zeros). Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Finally, Tables 5 and 6 turn to subsamples with regards to risk. We focus on General, Neonatal and Preventable measures of Mortality Rate, in this particular order, and present coefficients for High Risk births in odd columns and Low Risk in even columns, resulting in six columns per panel combining selected outcomes and risk types. We defined low risk birth as the one whose mother is not below 18 nor above 35 years old, a single fetus that is not preterm and without anomalies. In these specifications, we have removed the variables that define risk cited above from controls list, so models are different from the ones presented before.

Table 5, Panel A shows estimates for displacing and present, unlike previously, negative signals: for Neonatal and Preventable Mortality in High Risk pregnancies. In these cases, traveling improves survival chances for newborns as they are able to access facilities that are more suitable to treat them. For Low Risk pregnancies, on the other hand, we still observe a positive association to mortality.

Table 5: High Risk and Low Risk

Panel A: Indicator of displacement (1 = displaced)

Outcome	General		Neonatal		Preventable	
	(1)	(2)	(3)	(4)	(5)	(6)
1 Displaced	0.5665**	2.2091***	-1.0240***	0.8555***	-0.9879***	1.4546***
	(0.2343)	(0.0703)	(0.1846)	(0.0455)	(0.2015)	(0.0591)
Observations	8,996,533	24,575,589	8,996,533	24,575,589	8,996,533	24,575,589
R-squared	0.2175	0.0140	0.1939	0.0145	0.2217	0.0134
Mean Dep Var	27.416	5.315	16.325	2.219	20.244	3.747
Mean Exp Var	.302	.273	.302	.273	.302	.273
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Mother & Newborn Controls	Yes	Yes	Yes	Yes	Yes	Yes
Risk Controls	No	No	No	No	No	No
Type of Risk	High	Low	High	Low	High	Low

Panel B : Displaced distance

Outcome	General		Neonatal		Preventable	
	(1)	(2)	(3)	(4)	(5)	(6)
Distance (in 10 km)	0.3512***	0.2080***	-0.0140	0.0874***	-0.1387***	0.1131***
	(0.0270)	(0.0087)	(0.0213)	(0.0056)	(0.0232)	(0.0073)
Observations	8,996,533	24,575,589	8,996,533	24,575,589	8,996,533	24,575,589
R-squared	0.2175	0.0140	0.1939	0.0145	0.2217	0.0133
Mean Dep Var	27.416	5.315	16.325	2.219	20.244	3.747
Mean Exp Var	1.752	1.283	1.752	1.283	1.752	1.283
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Mother & Newborn Controls	Yes	Yes	Yes	Yes	Yes	Yes
Risk Controls	No	No	No	No	No	No
Type of Risk	High	Low	High	Low	High	Low

This table reports coefficients on several measures of infant mortality rate, estimating equation (1). Outcome variables (pairs of columns): general infant mortality, early neonatal mortality and infant mortality by preventable cause. Preventable and non-preventable classification uses CID-10 criteria. Panel A uses dummy indicating displacement was made (=1) or not (=0) as a regressor. Panel B uses the travelled distance by 10 kilometers and Panel C uses only displacers' distances (i.e. eliminating zeros). Sample was split in High Risk (odd columns) and Low Risk birth (even columns) according to mother's age, whether newborn was preterm, whether pregnancy was multiple and presence of anomalies. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

In Table 5, Panel B, nonetheless, neonatal mortality is non-significant in risky pregnancies (column 3). Displacing extra 10 kilometers still correlates negatively with mortality for preventable causes with high risk (column 5) and positively for others. Panel C, Table 6, does not alter qualitatively results. While High risk estimates remain on approximate levels, Low Risk estimates fall by at least half. Most contrasting, for Preventable mortality (column 6), .11 becomes .03. It is expected for correlations to be weaker since low risk pregnancies entail less need to displacements. Although 6 million women still displace and outcome mean does not lower, this is not related to displacing longer distances.

Table 6: High Risk and Low Risk - Cont'd

Panel C : Conditional displaced distance (only among displacers)

Outcome	General		Neonatal		Preventable	
	(1)	(2)	(3)	(4)	(5)	(6)
Distance (in 10 km)	0.4184***	0.1023***	0.0466	0.0445***	-0.1017***	0.0313***
	(0.0404)	(0.0125)	(0.0320)	(0.0082)	(0.0344)	(0.0105)
Observations	2,714,082	6,706,442	2,714,082	6,706,442	2,714,082	6,706,442
R-squared	0.2403	0.0278	0.2088	0.0280	0.2419	0.0262
Mean Dep Var	33.799	5.662	20.04	2.431	24.29	3.95
Mean Exp Var	5.791	4.696	5.791	4.696	5.791	4.696
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Mother & Newborn Controls	Yes	Yes	Yes	Yes	Yes	Yes
Risk Controls	No	No	No	No	No	No
Type of Risk	High	Low	High	Low	High	Low

This table reports coefficients on several measures of infant mortality rate, estimating equation (1). Outcome variables (pairs of columns): general infant mortality, early neonatal mortality and infant mortality by preventable cause. Preventable and non-preventable classification uses CID-10 criteria. Panel A uses dummy indicating displacement was made (=1) or not (=0) as a regressor. Panel B uses the travelled distance by 10 kilometers and Panel C uses only displacers' distances (i.e. eliminating zeros). Sample was split in High Risk (odd columns) and Low Risk birth (even columns) according to mother's age, whether newborn was preterm, whether pregnancy was multiple and presence of anomalies. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

6.2 Minimum distance to health infrastructure

First, we analyze the effect of the distance to a certain level of care on infant mortality. The minimum distance to Level-II and Level-III facilities increases the infant mortality rate. In a model with only time fixed effects as control variables, a one standard deviation increase in the minimum distance to Level-II facilities increases infant mortality by 0.32 deaths per 1000 live births. Worse, the minimum distance to Level-III facilities increases infant mortality by 0.43 deaths per 1000 live births, which represent a 4.4 percent increase in the infant mortality rate (Table 7, column (1)). The inclusion if mother and newborn characteristics and pregnancy risk variables in the model reduces the effect of Level-III facilities, indicating that mothers and children living further from Level-III facilities tend to have poorer socioeconomic and risk factors.

Table 7: Infant Mortality Models of Minimum Distance to Levels of Care

	(1)	(2)	(3)	(4)	(5)
Level I	-0.0583	0.0911	0.0868	0.0712	0.0965**
	(0.0766)	(0.0706)	(0.0746)	(0.0458)	(0.0454)
Level II	0.3225***	0.3241***	0.4035***	-0.1462	-0.0659
	(0.0894)	(0.0745)	(0.0808)	(0.1051)	(0.1058)
Level III	0.4258***	0.2645***	0.3695***	0.5216***	0.4849***
	(0.0915)	(0.0702)	(0.0715)	(0.1975)	(0.1837)
Observations	31,634,221	30,598,776	30,598,759	30,598,759	30,596,409
R-squared	0.0000	0.1181	0.1631	0.1636	0.1636
Mean Dep Var	11.41	11.158	11.158	11.158	11.158
Year FE	Yes	Yes	Yes	Yes	No
Mother & Newborn Controls	No	Yes	Yes	Yes	Yes
Risk Controls	No	No	Yes	Yes	Yes
Health region-year FE	No	No	No	Yes	Yes
Municipal controls	No	No	No	No	Yes

This table estimates the effect of the minimum distance to levels of care on 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. Clustered-robust standard errors are in parentheses. The cluster is at the municipal level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

The Level-II distance effect is robust to the inclusion of mother and newborn socioeconomic characteristics and pregnancy risk variables. Nevertheless, after controlling for health region trends, it becomes statistically insignificant. This result suggests that the effect of the distance to a Level-II facility on infant mortality is coming from health regions that were already reducing (or increasing) their mortality rates.

On the other hand, the health region-year fixed effects increase the magnitude of the Level-III coefficient, which suggests that regional trends were counteracting the effect of the distance to Level-III facilities on infant mortality. Finally, we add municipal characteristics to the model and find that the effect of the distance to a Level-III facility remains unaltered, thus showing the robustness of Level-III effects.

Table 8 shows the effect of the distance to the different levels of care on infant mortality measures. The results correspond to the model that includes all control variables. As we can see, the effect of the distance to a Level-III facility is concentrated on early neonatal and preventable deaths. While the coefficients of these outcome variables are statistically significant at 1%, those of late neonatal, post-neonatal and non-preventable deaths are not. Further, Table 9 shows that the effect of the distance to Level-III facilities is larger for high-risk pregnancies, and is concentrated on early and preventable deaths as well. The effect of the distance to Level-III facilities on early mortality is nearly 5 times higher for the group of high-risk pregnancies compared to the other group (1.4 versus 0.32). Likewise, the effect on preventable deaths among high-risk pregnancies nearly doubles that of low-risk pregnancies. These results are consistent with the literature that finds that access to medical technology is relevant for very low birth weight and very premature babies, related to high-risk pregnancies (Lorch et al., 2012; Barfield et al., 2012; Lorch et al., 2021).

Table 8: Minimum Distance to Levels of Care Models for Infant Mortality Measures

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome	General	Early Neonatal	Late Neonatal	Post-neonatal	Preventable	Non-preventable
Level I	0.0965**	0.0673*	0.0104	0.0188	0.0932**	0.0034
	(0.0454)	(0.0352)	(0.0147)	(0.0221)	(0.0394)	(0.0189)
Level II	-0.0659	-0.0300	-0.0328	-0.0031	-0.1903**	0.1244***
	(0.1058)	(0.0856)	(0.0308)	(0.0492)	(0.0908)	(0.0415)
Level III	0.4849***	0.6182***	-0.0580	-0.0754	0.4926***	-0.0078
	(0.1837)	(0.1492)	(0.0607)	(0.0955)	(0.1608)	(0.0758)
Observations	30,596,409	30,596,409	30,596,409	30,596,409	30,596,409	30,596,409
R-squared	0.1636	0.1583	0.0265	0.0101	0.1634	0.0488
Mean Dep Var	11.158	5.96	1.917	3.281	8.093	3.065
Year FE	No	No	No	No	No	No
Mother & Newborn Controls	Yes	Yes	Yes	Yes	Yes	Yes
Risk Controls	Yes	Yes	Yes	Yes	Yes	Yes
Health region-year FE	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). Outcomes of columns (2) to (4) are mortality components by age of death: early neonatal (six days), late neonatal (7 to 30 days), post-neonatal (after 30 days). Outcomes of columns (5) and (6) are infant mortality cases by cause: preventable and non-preventable. Preventable and non-preventable classification uses CID-10 criteria. 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. Clustered-robust standard errors are in parentheses. The cluster is at the municipal level. *** p<0.01, ** p<0.05, * p<0.1.

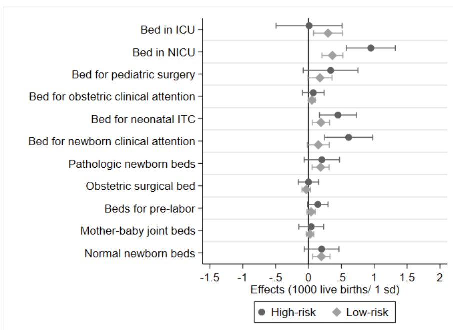
Table 9: Minimum Distance to Levels of Care Models for Infant Mortality Measures by Pregnancy Risk

Outcomes	(1) General	(2) Early Neonatal	(3) Late Neonatal	(4) Post-neonatal	(5) Preventable	(6) Non-preventable
Panel A: High-risk pregnancies						
Level I	0.1635	0.1477*	0.0044	0.0115	0.1706*	-0.0071
	(0.1135)	(0.0883)	(0.0440)	(0.0523)	(0.0988)	(0.0530)
Level II	0.0074	0.0514	-0.1295*	0.0855	-0.3100	0.3174***
	(0.2353)	(0.2030)	(0.0765)	(0.1070)	(0.1983)	(0.1045)
Level III	0.7279*	1.4011***	-0.3372**	-0.3361	0.7412**	-0.0133
	(0.4078)	(0.3483)	(0.1576)	(0.2225)	(0.3402)	(0.2067)
Observations	8,276,971	8,276,971	8,276,971	8,276,971	8,276,971	8,276,971
R-squared	0.2479	0.2185	0.0380	0.0182	0.2454	0.0768
Mean Dep Var	27.252	16.178	4.898	6.176	20.072	7.18
Year FE	No	No	No	No	No	No
Mother & Newborn Controls	Yes	Yes	Yes	Yes	Yes	Yes
Risk Controls	Yes	Yes	Yes	Yes	Yes	Yes
Health region-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Municipal controls	Yes	Yes	Yes	Yes	Yes	Yes
Panel B: Low-risk pregnancies						
Level I	0.0416	0.0127	0.0096	0.0192	0.0434	-0.0019
	(0.0363)	(0.0245)	(0.0103)	(0.0200)	(0.0298)	(0.0157)
Level II	-0.1243	-0.0773	-0.0008	-0.0462	-0.1616**	0.0373
	(0.0953)	(0.0640)	(0.0252)	(0.0495)	(0.0816)	(0.0339)
Level III	0.4341***	0.3294***	0.0619	0.0428	0.4275***	0.0066
	(0.1569)	(0.1078)	(0.0452)	(0.0883)	(0.1392)	(0.0627)
Observations	22,319,438	22,319,438	22,319,438	22,319,438	22,319,438	22,319,438
R-squared	0.0073	0.0078	0.0012	0.0011	0.0071	0.0011
Mean Dep Var	5.19	2.17	0.81	2.208	3.651	1.539
Year FE	No	No	No	No	No	No
Mother & Newborn Controls	Yes	Yes	Yes	Yes	Yes	Yes
Risk Controls	Yes	Yes	Yes	Yes	Yes	Yes
Health region-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Municipal controls	Yes	Yes	Yes	Yes	Yes	Yes

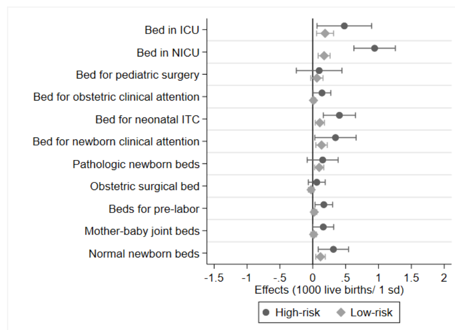
This table estimates the effect of the minimum distance to levels of care on different measures of infant mortality using equation (2). Outcomes of columns (2) to (4) are mortality components by age of death: early neonatal (six days), late neonatal (7 to 30 days), post-neonatal (after 30 days). Outcomes of columns (5) and (6) are infant mortality cases by cause: preventable and non-preventable. Preventable and non-preventable classification uses CID-10 criteria. 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. Clustered-robust standard errors are in parentheses. The cluster is at the municipal level. *** p<0.01, ** p<0.05, * p<0.1.

Finally, we estimated the effect of the distance to specific infrastructure, equipment, and human resources items on different measures of infant mortality (Figures 8, 9 and 10). 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. Distance to infrastructure and human resources is more relevant than the distance to equipment. In particular, an increase of one standard deviation in the minimum distance to NICU, pathological newborn, and intermediate care beds raises the infant mortality rate of over 0.5 deaths per 1000 live births. These effects are larger for high-risk pregnancies. Similarly, the distance to more integrated health staff, including pediatricians, general physicians, phonoaudiologists, and social workers, is positively correlated with higher infant mortality rates.

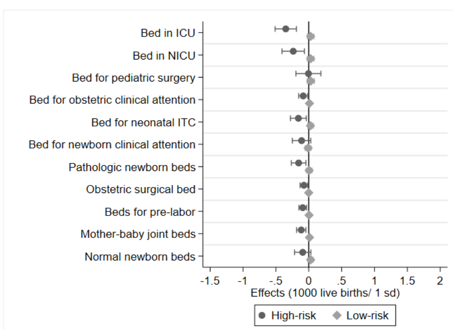
Figure 8: Minimum Distance to Infrastructure Effects on Infant Mortality Measures by Pregnancy Risk



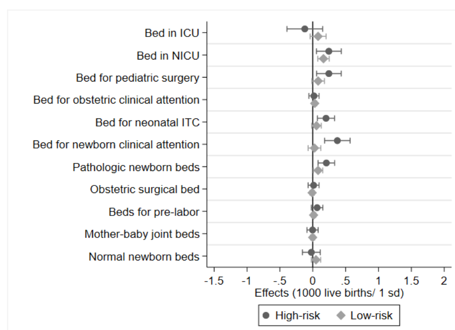
(a) General



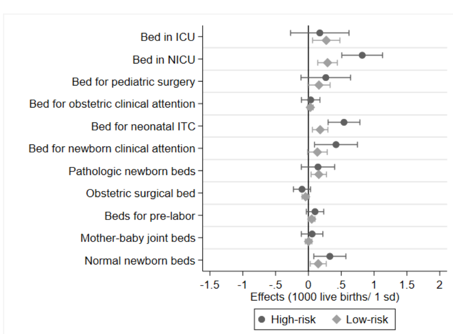
(b) Early Neonatal



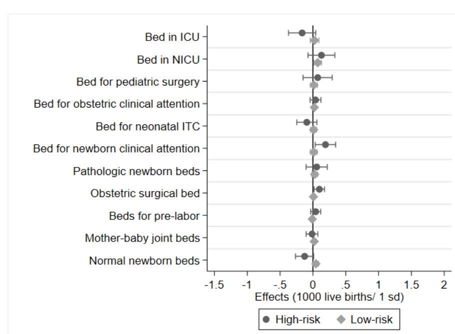
(c) Late Neonatal



(d) Post-neonatal

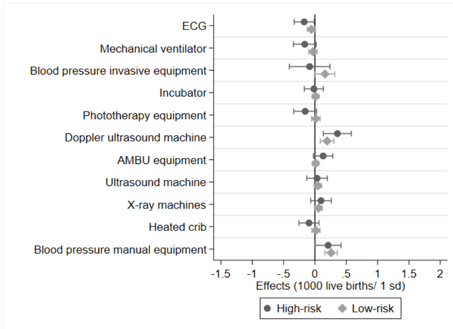


(e) Preventable

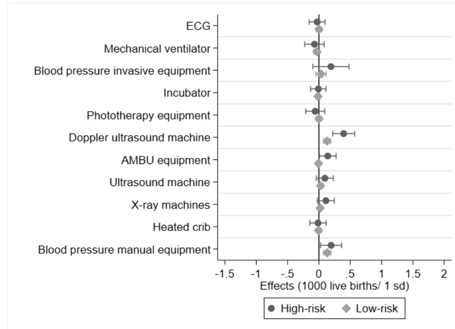


(f) Non-preventable

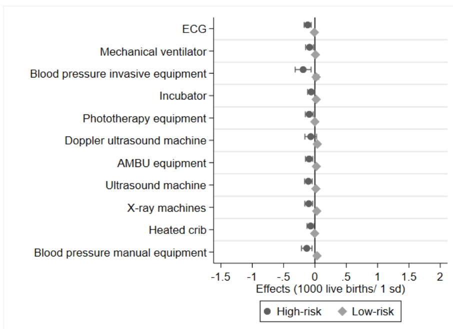
Figure 9: Minimum Distance to Equipment Effects on Infant Mortality Measures by Pregnancy Risk



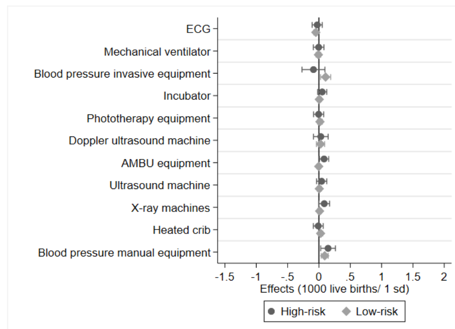
(a) General



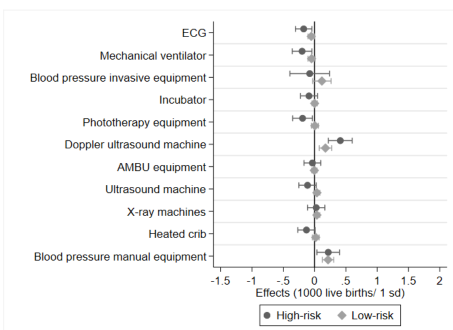
(b) Early Neonatal



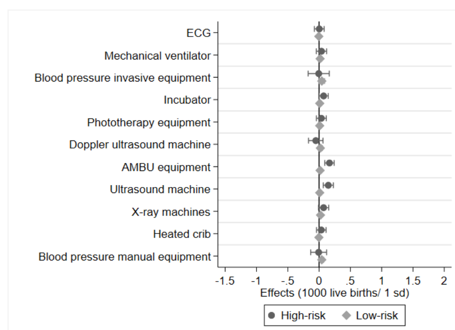
(c) Late Neonatal



(d) Post-neonatal

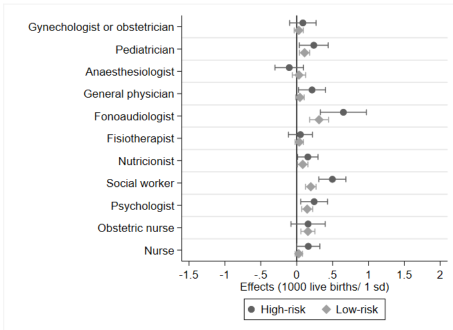


(e) Preventable

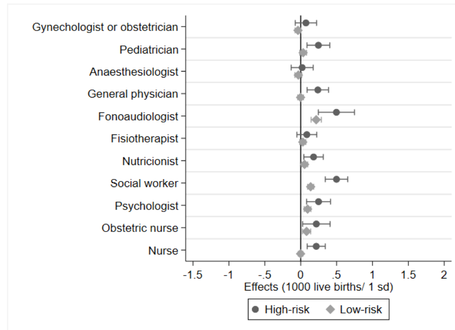


(f) Non-preventable

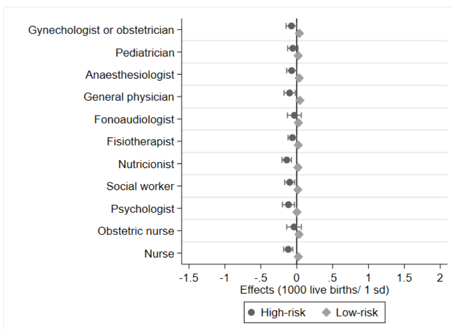
Figure 10: Minimum Distance to Human Resources Effects on Infant Mortality Measures by Pregnancy Risk



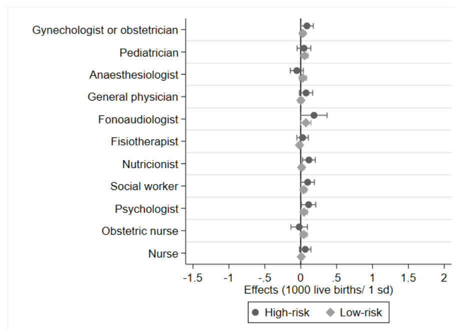
(a) General



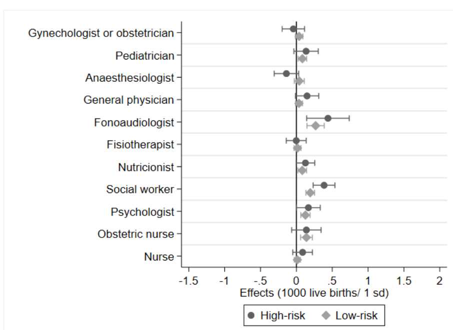
(b) Early Neonatal



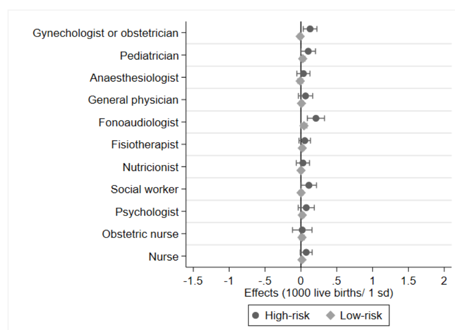
(c) Late Neonatal



(d) Post-neonatal



(e) Preventable



(f) Non-preventable

7 Conclusion

This paper analyses the effect of the distance mothers travel to give birth on infant mortality in Brazil. We find that traveled distance and infant mortality remain positively correlated under different empirical strategies, after controlling for several socioeconomic and risk factors. Consistently, the distance to the closest Level-III facility, infrastructure, equipment or human resources increases infant mortality, particularly among high-risk pregnancies, early neonatal and preventable deaths.

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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):								
≤ 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:								
≤ 0	76.2	246	60.2	1019	17.1	50	6.5	10
0-2	20.1	65	25.0	423	22.2	65	3.9	6
>2	3.7	12	14.9	252	60.8	178	89.6	138
Very low weight births								
≤ 0	66.9	216	50.6	858	13.0	38	5.2	8
0-1	17.0	55	20.2	342	10.2	30	1.3	2
1-4	12.7	41	16.8	285	15.0	44	0.6	1
>4	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, 2022a). 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. (2022)