Online appendix to accompany
Maternal Dengue and Health Outcomes of Children
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Appendix A Additional Tables and Figures

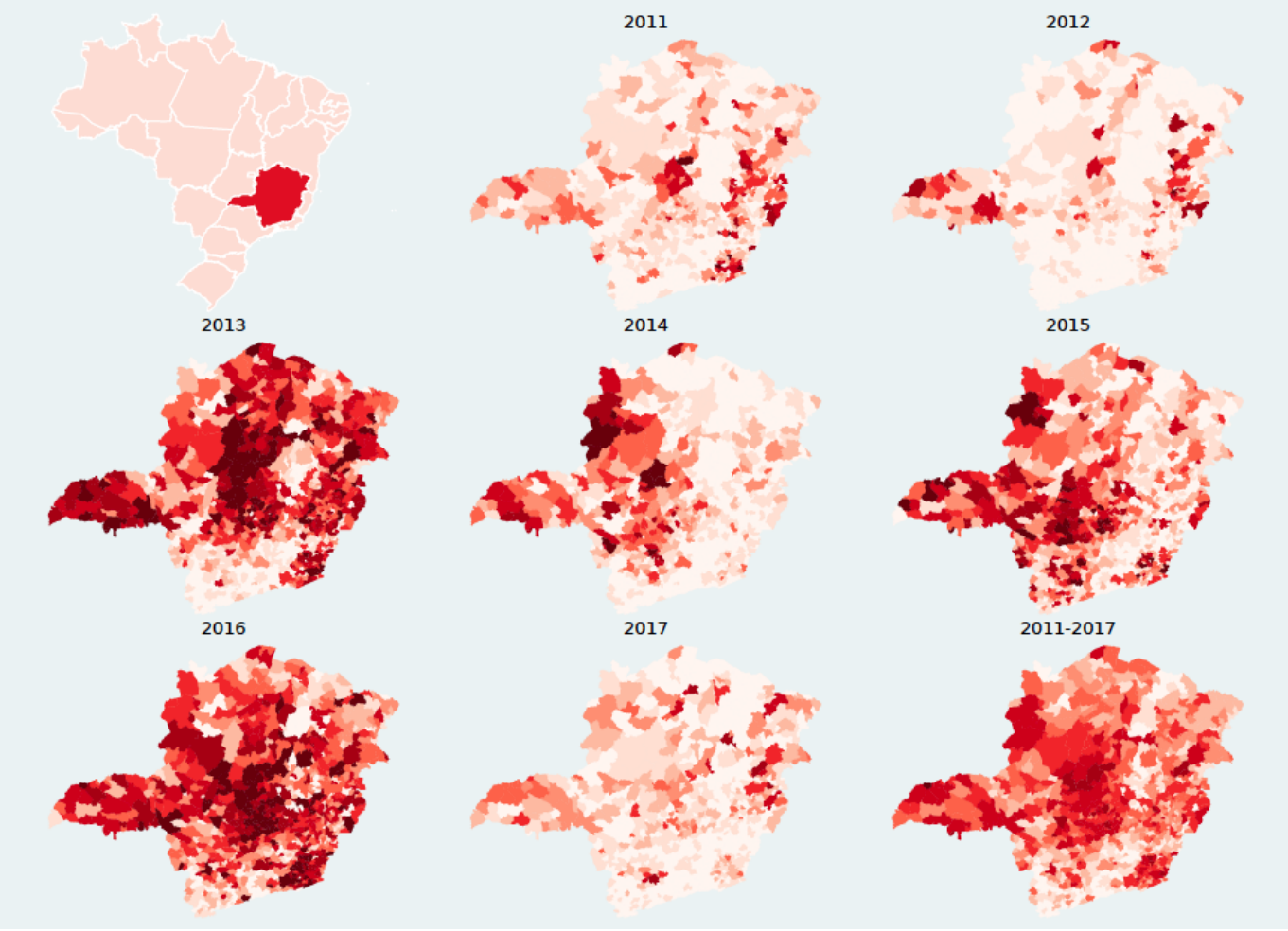


Figure A1: Spacial Distribution of Dengue Cases in the State of Minas Gerais, Brazil

Note: To compare the incident across years, we normalize the shading using the year with the highest cases in 2016. This means that the same shading of red across different years indicates the same dengue incident rate.

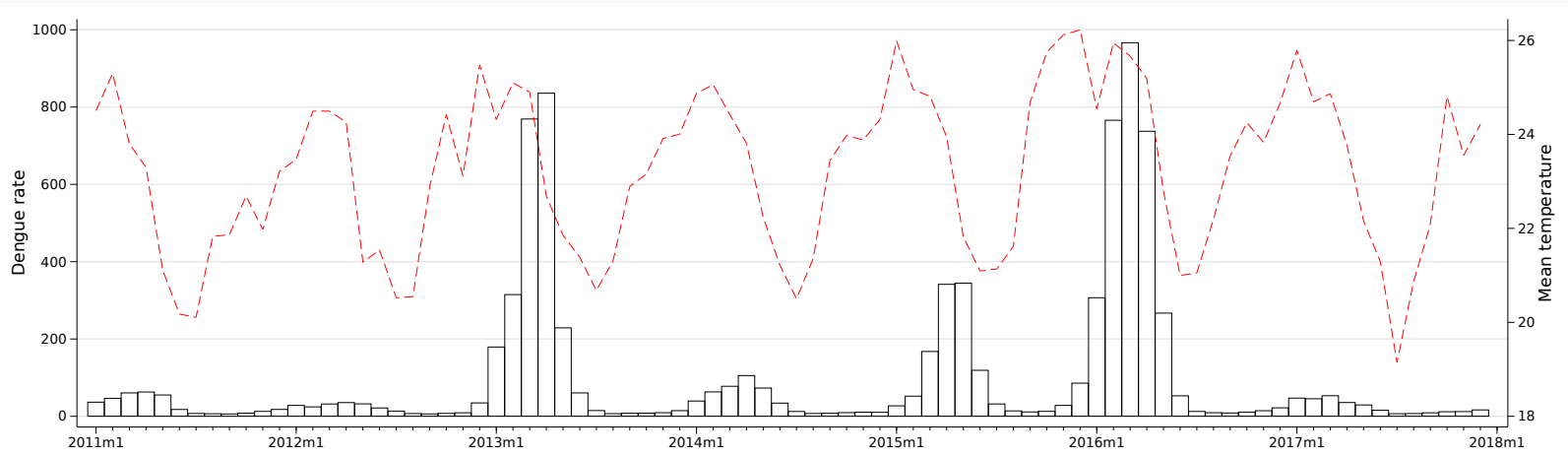


Figure A2: Monthly Dengue Rate and Average Temperature from 2011 to 2017 in Minas Gerais

Note: The dashed red line depicts mean monthly temperature. The bars depict mean monthly dengue rates per 1,000 population.

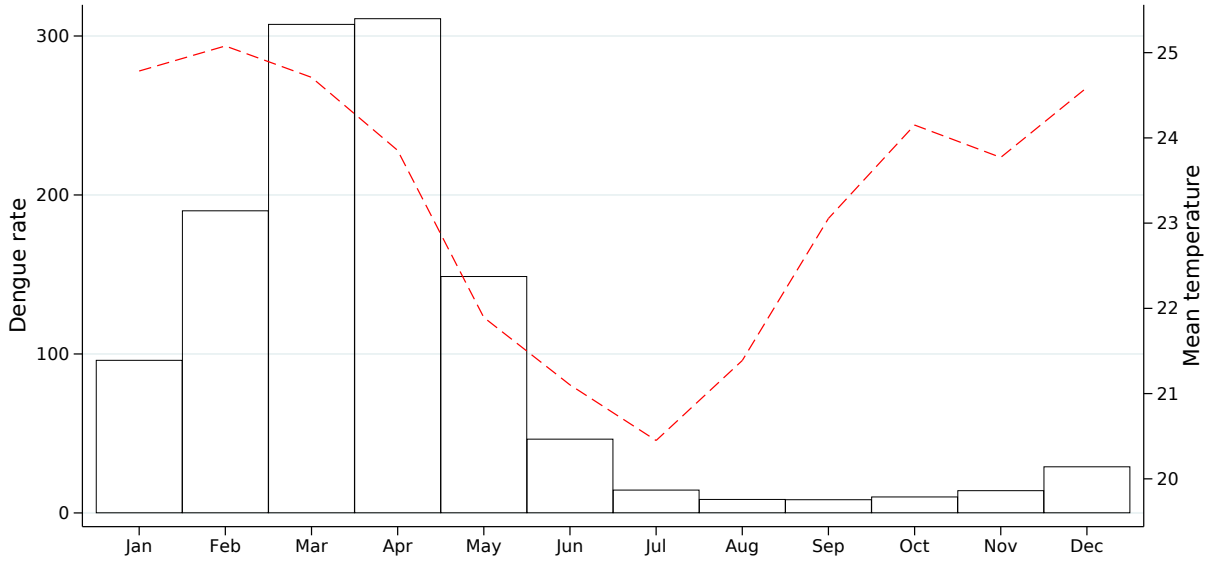


Figure A3: Dengue Rate and Average Temperature by Calendar Month

Note: The dashed red line depicts mean monthly temperature. The bars depict mean monthly dengue rates per 1,000 population.

Table A1: Effect of Dengue on Gestational Length by trimester

	Gestatation (days)	*Gestation (<259 days)*	*Gestation (<224 days)*	*Gestation (<196 days)*
	(1)	(2)	(3)	(4)
Dengue	−0.012	−0.006	0.007	0.005
(1st trimester)	(0.650)	(0.014)	(0.006)	(0.003)
Dengue	−0.870	0.003	0.010	0.001
(2nd trimester)	(0.691)	(0.013)	(0.007)	(0.004)
Dengue	−0.555	0.021	0.014	−0.000
(3rd trimester)	(0.749)	(0.015)	(0.006)**	(0.004)
Mean dep. var.	269.854	0.103	0.013	0.003
Mothers	136,788	136,788	136,788	136,788
Observations	281,497	281,497	281,497	281,497

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Robust standard errors are clustered at the mother level in parentheses.

Note: The analysis includes mothers over the period between 2011 and 2017. *Gestation* is reported in days. Columns 2, 3, and 4 are dummies for early, very early, and extremely early delivery, respectively. Explanatory variables *Dengue (1st trimester)*, *Dengue (2nd trimester)* and *Dengue (3rd trimester)* indicate the trimester of pregnancy the mother was infected with dengue. All regressions include month of conception fixed-effects and maternal fixed-effects and the full set of controls (for a detailed list of controls, see Table 2 note).

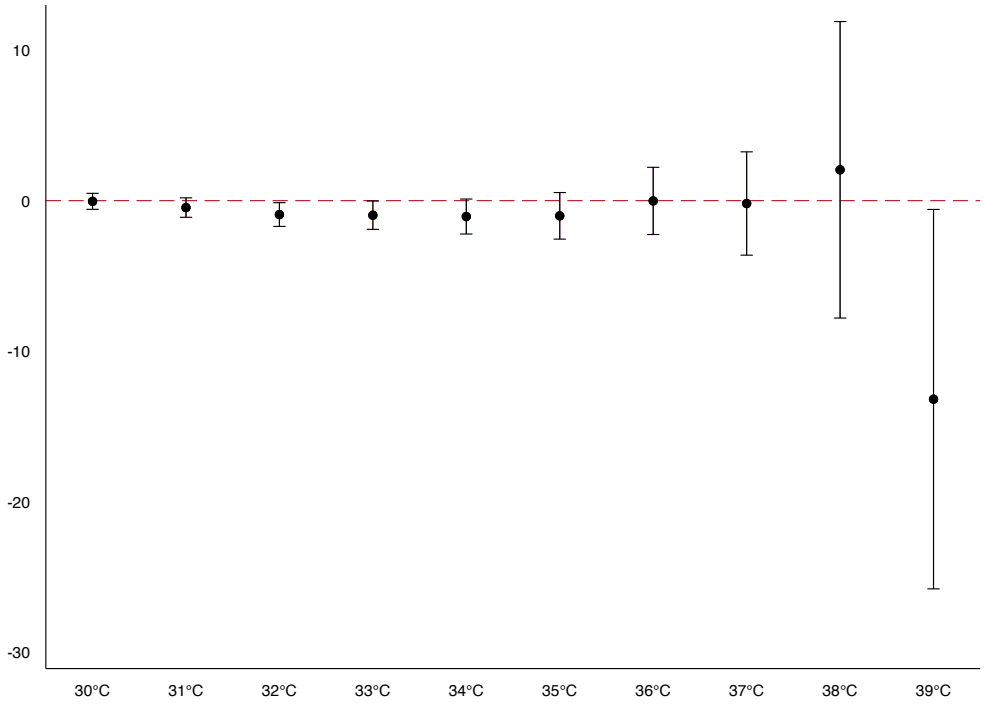


Figure A4: Effect of Temperature on Dengue Rate

Note: Dependent variable is monthly dengue rate at the municipality level. Explanatory variables are the number of days in a month with maximum temperature higher than or equal to 30°C, 31°C,..., 39°C. All regressions include month and municipality fixed-effects.

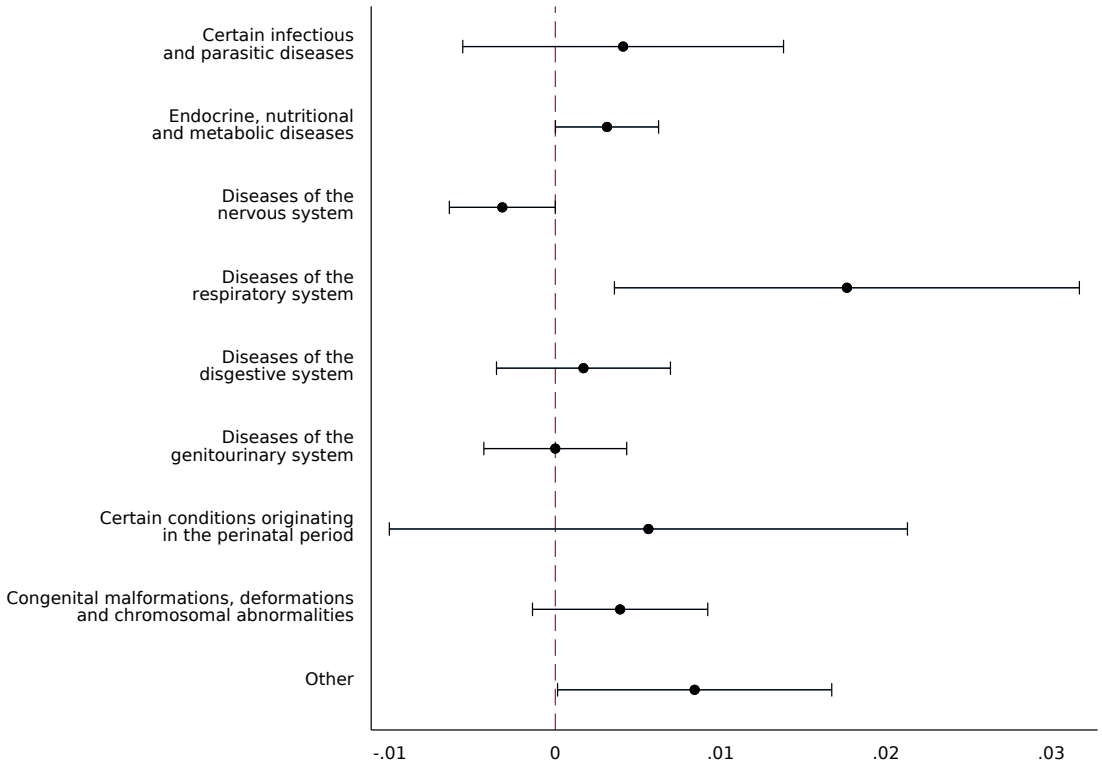


Figure A5: Effect of Dengue on Hospitalization by Cause of Hospitalization

Note: Causes of hospitalization follow the International Statistical Classification of Diseases and Related Health Problems (ICD-10). We report the coefficients for the most common reasons for hospitalization (more than 2% incidence in our sample). The remaining causes are grouped in the category "Other".

Table A2: Effect of Dengue on Additional Outcomes by trimester

	Emergency C-section	*APGAR (1st minute)*	*APGAR (5th minute)*	*Prenatal visits*	*Female*	*Mortality (1 week)*	*Mortality (4 weeks)*	*Mortality (22 weeks)*	*Mortality (1 year)*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dengue	0.011	−0.031	−0.042	0.265	−0.005	0.006	0.003	0.001	0.001
(1st trimester)	(0.015)	(0.061)	(0.036)	(0.106)**	(0.025)	(0.004)	(0.004)	(0.005)	(0.005)
Dengue	0.005	−0.025	−0.034	0.261	0.045	0.002	0.001	0.000	−0.001
(2nd trimester)	(0.016)	(0.063)	(0.038)	(0.109)**	(0.025)*	(0.003)	(0.003)	(0.003)	(0.004)
Dengue	0.008	0.002	0.035	0.087	0.009	0.001	0.002	0.004	0.002
(3rd trimester)	(0.017)	(0.066)	(0.045)	(0.114)	(0.026)	(0.004)	(0.005)	(0.005)	(0.006)
Mean dep. var.	0.180	8.448	9.381	7.671	0.482	0.004	0.005	0.006	0.007
Mothers	136,788	131,140	131,290	134,101	136,742	136,788	136,788	136,788	136,788
Observations	281,497	269,676	270,003	275,754	281,403	281,497	281,497	281,497	281,497

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Robust standard errors are clustered at the mother level in parentheses.

Note: The analysis includes mothers over the period between 2011 and 2017. *Emergency C-section* is a dummy indicating if the C-section happened after labor began. Explanatory variables *Dengue (1st trimester)*, *Dengue (2nd trimester)* and *Dengue (3rd trimester)* indicate the trimester of pregnancy the mother was infected with dengue. All regressions include month of conception fixed-effects and maternal fixed-effects and the full set of controls (for a detailed list of controls, see Table 2 note).

Appendix B The Temporal and Spatial Distribution of Dengue Cases

There is substantial temporal and geographic variation in the cases of dengue in Brazil. In Figure A1, we display dengue cases across municipalities in the state of Minas Gerais for each year in our sample and aggregated for the entire period. Municipalities with darker shades of red have higher dengue incident rates. Two features stand out. First, there is substantial variation in dengue cases across space and time, indicating clusters of local outbreaks in different years. Second, there is substantial variation in the overall incidence rate year-by-year, indicated by darker shades in 2013 and 2016 compared to all other years. In Figure A2 we document the temporal variation in dengue. The figure confirms two large dengue outbreaks in 2013 and 2016, with a smaller outbreak in 2015, and years of relative calm in between.[1] The figure also reveals strong seasonality in dengue cases, roughly in line with lagged seasonal temperature variation. Seasonality is even more evident in Figure A3, where we plot dengue rates by calendar month over our sample period. Dengue cases peak in March and April and reach lows during the months of July to November.[2] We provide additional information on the evolution of the dengue virus in Brazil before the sample period in the following Appendix section C.

[1] This is closely matched in our maternal fixed-effects estimation sample with a peak in infections in 2013 and 2016, accounting for 73% of all infections. This is also virtually identical to the infection rates for all mothers, with 73% occurring in these two years.

[2] Seasonal patterns are confirmed for many other countries suffering from dengue, for example, Thailand (Polwiang (2020)) and Bangladesh (Hossain et al. (2022)).

Appendix C Evolution of Dengue Virus in Brazil

Before the 1970s, the dengue virus was endemic only in a very small number of countries and with a small number of overall infections. Since then, dengue has expanded very rapidly and is now endemic in more than 100 countries, with an estimated half a billion infections every year on average and putting half of today's world population at risk of disease (Bhatt et al. (2013), Brady et al. (2012)). In Brazil, dengue has been endemic since the 1990s—after a decades-long absence—with an increase in the prevalence and substantial temporal (including seasonal) and spatial variation in the incidence from year to year and across Brazilian municipalities (Andrioli et al. (2020)).

The rapid global expansion of dengue was driven by a combination of increasing human mobility through improved transport links and increased population density and urbanization, as well as inadequate urban infrastructure (Wilder-Smith et al. (2019)). These are also the reasons for dengue spreading rapidly in Brazil starting in the 1990s and dengue now being hyper-endemic, resulting in the co-circulation of the four serotypes (Conrado Guerra Nunes et al. (2019)). Dengue is on the list of compulsory notifiable diseases in Brazil, and there is an efficient reporting system in place. To limit the spread of *Aedes* mosquitoes, Brazil is operating one of the largest dengue vector control programs in the world, with mixed success (Augusto et al. (2016), Araújo et al. (2015)). Vector control strategies are based on a combination of community mobilization to reduce breeding opportunities for mosquitoes[3] and the widespread application of insecticides.

While dengue fever has a relatively low mortality rate compared to other tropical infectious diseases, in particular yellow fever and malaria, severe dengue has an elevated risk of mortality of approximately 4% (Andrioli et al. (2020)). There are currently four distinct serotypes of the virus in circulation that differ genetically and serologically. Primary infection with one serotype is believed to lead to lifelong immunity to the same serotype but not to other serotypes. Secondary infection with a different serotype is, on the contrary, associated with an increased risk of developing severe dengue. This is suspected to be caused by

[3]This includes disposing of manmade habitats that can hold water in private households, applying insecticides to outdoor water storage containers, and improving waste collection, among other activities (Eisen et al. (2009)).

a complex immune response and the mixture of neutralizing and binding antibodies, where neutralizing antibodies are serotype-specific, but binding antibodies are not (Murugesan and Manoharan (2020)).[4]

After many years of research and testing, in 2015, the first dengue vaccine was licensed and received regulatory approval in Brazil and 19 other countries. Despite evidence on the cost-effectiveness for Brazil (Shim (2017)), uptake has been relatively slow. This is possibly due to the low mortality of dengue and some uncertainty on the safety related to the excess risk of developing severe dengue in seronegative vaccine recipients (Sridhar et al. (2018)). Besides vaccines and traditional vector control activities, there are promising advances in modeling the dengue vectors to reduce the spread of dengue through genetic engineering and allowing the mosquitoes to develop immunity to the virus (Buchman et al. (2019)) or by infecting the mosquitoes with a bacterium which can prevent the dengue virus from replicating (Frentiu et al. (2014)).

[4]This feature of the immune response also provides for an extra obstacle in the development of a dengue vaccine, as a successful vaccine candidate needs to give immunity to all prevalent dengue serotypes (Payne (2017); Wilder-Smith et al. (2019)).

Appendix D Data sources and descriptive statistics

D.1 Birth records

The birth records from SINASC data collect detailed information on newborn and mother characteristics and the mode of delivery. Newborn characteristics include BW, 1st and 5th minute APGAR scores, and sex. Mother characteristics include age, previous live births and stillbirths, occupation, marital status, and education. Information on the pregnancy and delivery includes the number of prenatal visits, type of delivery (vaginal vs. C-section), and information on whether the C-section was planned or due to an emergency.

We present summary statistics for the entire sample of singleton births and the within-mother sample in Table 1. Mean BW in our sample is 3,160 grams, and the incidence of low BW (<2,500 grams), very low BW (<2,000 grams), and extremely low BW (<1,500 grams) is 8%, 1% and 0.4%, respectively.[5] Mean gestational length is 270 days (just over 38 weeks), and the fraction of pregnancies with very preterm delivery (<32 weeks) is 1.3%.[6] In addition to information on health outcomes of live births, SINASC data also contain information on pregnancy and delivery. Prenatal visits are free in the public health system, and antenatal care is generally of high quality in Brazil (Victora et al. (2011)). On average, women have around eight prenatal care visits.[7] 42.7% of deliveries were through C-section, and about 20% were initiated after labor began, thus defined as emergency C-section.[8]

Table 1 also presents the summary characteristics of the mothers. Their mean age is 27 years; 20% of mothers are 20 or younger. More than 50% of mothers declare themselves mixed race, 36% are white, and 8% are black. Detailed information on the marital status of the mother is also provided. 39% are single, 44% are married, and 14% are in a stable union. As to their educational background, 19% have high education.

The birth and pregnancy characteristics of the maternal fixed-effects sample we use for the main analysis are very similar to the whole sample. As the within-mother sample is derived

[5] These figures are similar to recent US data on singleton births, with an incident of 6.60 and 1.09% for the fraction of low and very low BW deliveries, respectively (Martin et al. (2019)).

[6] We calculate gestational length by using the information on the date of conception and date of delivery.

[7] These include extensive screening for risk factors, including diabetes, pre-eclampsia, and underlying infections, plus ultrasound scans of the fetus.

[8] Brazil has well-documented high rates of planned Caesarean section delivery (Barros et al. (1991), Rudey et al. (2020)).

from mothers with at least two births over the period, this excludes first-time mothers with at most one child and mothers with multiple births but outside the period from 2011 to 2017. Mother characteristics are also largely very similar, in particular with respect to predetermined characteristics such as educational background and self-declared skin color.

D.2 Infant and child mortality

For any death occurring during the first year of life, SIM data is linked to the birth records from SINASC. We calculate any child death for different periods after births and record early neonatal (1 week), neonatal (4 weeks), 22 weeks and 52 weeks mortality. 0.38% of live-born children die within a week, making up about half of all infant deaths (0.71% of live births).

D.3 Hospitalization

We link birth records with subsequent hospitalizations three years after birth and distinguish between regular admission to hospital and admission to intensive care units (including neonatal intensive care for the first month after birth). For the merge, we use the information on the newborns' date of birth, sex, and address at the time of delivery, limiting the fraction of successfully linked hospitalization records compared to the link between dengue and birth records. The incidence of hospital admission in the first year after birth is just under 10% and drops to 2 and 1% in the second and third years. Neonatal ICU admissions account for about 18% of all hospital admissions in the first year. A unique feature of the hospitalization records is that it includes information on the primary cause of hospitalization (using the ICD-10 classification), length of hospital stay and each hospital admission cost. The average hospital stay in the first year is just over 10 days, with an average price of R$3,327.95. There is a substantial variation in the hospitalization costs, with the highest observed costs over R$269,488, with a median of R$606.43.

D.4 Dengue

We link dengue infections to mothers using individual identifiers. This has the advantage of being able to link mothers to dengue infections during pregnancy and infections that

occur with women who gave birth twice over our period but contracted dengue outside of pregnancy. We focus on 'classic' dengue and drop cases of 'severe' dengue from our sample.[9] Severe dengue is rare (0.22%) and unsurprisingly, due to its severity, may affect the unborn children of mothers suffering from its complications.

In this paper, we are interested in the effect *classic* dengue, comprising the vast majority of dengue cases, has on the health of unborn children. We hence remove a small number of cases clinically identified with symptoms of severe dengue (0.22%), mostly with hemorrhagic complications. An infection of a particular dengue serotype leads to individuals being immune to the same strain but increases the risk for complications when infected with different dengue serotypes, potentially leading to changes in the behavior of expectant mothers with the knowledge of a previous infection.

We also link the birth records with another notifiable disease, Zika virus. Zika is in the same family as the dengue virus and was first identified in the northeast of Brazil in 2015. From the end of 2015, every laboratory-confirmed Zika infection was included in the *Notifiable Diseases Information System*, collecting the same information as for dengue infections. Because of the risk of microcephaly in children born to mothers infected with Zika during pregnancy, the outbreak received considerable attention from health authorities in Brazil and beyond. While the spread of Zika was largely concentrated in the northeast region of Brazil, which accounted for 61.1% of cases, the number of cases in Minas Gerais, the Brazilian state for which we have data, saw only a very small number of Zika cases (and cases of microcephaly) in comparison. In our sample, 8 cases of Zika during pregnancy occurred. We removed these mother observations from our estimation sample.

D.5 Temperature data

The temperature data ERA5 from ECMWF consists of reanalysis data combining past observations with models to generate consistent time series of temperature variables at a 0.25×0.25 degrees grid. We follow the literature to assign a weighted average temperature to each of the 843 municipalities by using an inverse-distance weighted average of all weather grid points

[9] Severe dengue is associated with any number of complications linked with severe bleeding, organ impairment, and/or plasma leakage and can have life-threatening consequences. Severe dengue has been associated with repeat infection by other dengue serotypes after the initial infection.

within a 50 km range of the municipality centroid (Rocha and Soares (2015)). Figure A2 depicts the daily average temperature over time for the period 2011 to 2017. Mean daily temperature over this period is 23.2°C with a minimum of 11.6°C and a maximum average temperature of 33.5°C. The highest maximum daily temperature recorded in the data is 40.7°C. While less pronounced due to the proximity to the equator, there is still considerable variability over the year, as can be seen in Figure A3, with the highest average temperatures in February and the lowest in July.

Appendix E Heterogeneous effects

To learn whether the effect of maternal dengue may differ by mother characteristics, we split the sample of mothers using information on their age, race, marital status, and education. For time-varying characteristics (age, marital status, and education) we use their values at the first pregnancy we observe to split the sample. We report the results from this exercise in Table E3. First, we look at three age groups of mothers separately, where we define those age groups so that all birth observations for each mother meet the age criteria. This means that for the first group, we look at estimates for mothers 20 years and younger at last observed birth; for the second group we use mothers with all births between ages 21 and 35; and for the last group we use mothers older than 35 for the first observed birth.[10] We find that the effect of dengue infections during pregnancy is more pronounced for younger mothers, with the strongest effect for mothers aged 20 and under (-56 grams), but given the smaller sample, the coefficient is only marginally significant. This may either indicate a medical vulnerability of younger mothers in line with findings in the medical literature on the higher rate of low BW births among this age group and/or age being a proxy for socioeconomic background, with younger mothers being over represented with regard to a more deprived economic status. The effect for mothers above the age of 35 is very close to zero and insignificant. We find a similar picture for low BW. The effects for the older age groups are smaller. We find a similar pattern for the low BW classifications, with the most pronounced effects for low BW and extremely low BW for the group of younger mothers. When splitting the sample by mothers'

[10] This means we lose a small number of observations, where mothers have births falling outside these age ranges.

self-declared color of skin, we find slightly more pronounced effects for non-white mothers, both for BW and for low BW. We do not find any systematic differences by marital status, with coefficients being very close for married and unmarried mothers. Finally, we split the sample by mothers' education. We find stronger but insignificant effects on BW for mothers with higher levels of education but more pronounced effects on low BW for mothers with lower levels of education, possibly indicating diverging effects by educational background at different parts of the distribution. Given the much-reduced sample sizes, the estimates are nevertheless imprecise.

Table E3: Heterogeneity Analysis

Panel A - Birth Weight

	Mother's age			*Mother's race*		*Mother's marital status*		*Mother's education*	
	20 or less	*21 to 35*	*36 and beyond*	*White*	*Non-white*	*Married*	*Not married*	*Low*	*High*
Dengue	−55.971	−14.833	−28.329	−22.042	−35.627	−25.525	−24.377	−26.600	−43.630
(pregnancy)	(29.159)*	(14.797)	(76.582)	(27.533)	(15.074)**	(18.142)	(17.162)	(12.307)**	(35.144)
Mean dep. var.	3,113.303	3,194.305	3,214.501	3,177.668	3,172.161	3,197.004	3,146.790	3,169.481	3,198.518
Mothers	22,419	77,887	4,119	33,215	71,642	62,879	46,434	105,581	22,421
Observations	46,054	158,651	8,286	67,491	147,691	127,733	95,955	218,054	45,313

Panel B - Low Birth Weight

	Mother's age			*Mother's race*		*Mother's marital status*		*Mother's education*	
	20 or less	*21 to 35*	*36 and beyond*	*White*	*Non-white*	*Married*	*Not married*	*Low*	*High*
Dengue	0.036	0.010	−0.031	0.021	0.022	0.006	0.020	0.014	0.000
(pregnancy)	(0.019)*	(0.009)	(0.046)	(0.016)	(0.009)**	(0.011)	(0.011)*	(0.007)*	(0.022)
Mean dep. var.	0.089	0.068	0.069	0.068	0.076	0.065	0.083	0.076	0.061
Mothers	22,419	77,887	4,119	33,215	71,642	62,879	46,434	105,581	22,421
Observations	46,054	158,651	8,286	67,491	147,691	127,733	95,955	218,054	45,313

Panel C - Very Low Birth Weight

	Mother's age			*Mother's race*		*Mother's marital status*		*Mother's education*	
	20 or less	*21 to 35*	*36 and beyond*	*White*	*Non-white*	*Married*	*Not married*	*Low*	*High*
Dengue	0.003	0.005	−0.019	0.015	0.005	0.005	0.004	0.006	0.013
(pregnancy)	(0.008)	(0.003)	(0.019)	(0.007)**	(0.004)	(0.004)	(0.004)	(0.003)*	(0.008)
Mean dep. var.	0.010	0.008	0.011	0.008	0.009	0.008	0.010	0.009	0.008
Mothers	22,419	77,887	4,119	33,215	71,642	62,879	46,434	105,581	22,421
Observations	46,054	158,651	8,286	67,491	147,691	127,733	95,955	218,054	45,313

Panel D - Extremely Low Birth Weight

	Mother's age			*Mother's race*		*Mother's marital status*		*Mother's education*	
	20 or less	*21 to 35*	*36 and beyond*	*White*	*Non-white*	*Married*	*Not married*	*Low*	*High*
Dengue	0.005	0.004	−0.021	0.004	0.004	0.002	0.003	0.003	0.010
(pregnancy)	(0.006)	(0.002)*	(0.019)	(0.005)	(0.003)	(0.003)	(0.003)	(0.002)	(0.006)
Mean dep. var.	0.003	0.003	0.004	0.003	0.003	0.003	0.004	0.003	0.003
Mothers	22,419	77,887	4,119	33,215	71,642	62,879	46,434	105,581	22,421
Observations	46,054	158,651	8,286	67,491	147,691	127,733	95,955	218,054	45,313

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Robust standard errors are clustered at the mother level in parentheses.

Note: The analysis includes mothers over the period between 2011 and 2017. Explanatory variable *Dengue(pregnancy)* indicates whether the mother had dengue during pregnancy. All regressions include month of conception fixed-effects and maternal fixed-effects and the full set of controls (for a detailed list of controls, see Table 2 note).

Appendix F Additional analysis

In this appendix, we systematically probe the main estimates further in addition to the sensitiveness checks provided in Section 5. We also test sensitivity to additional sample restrictions, provide a falsification exercise for the main results, and discuss robustness of the hospitalization results in line with the sensitivity analysis of the main outcomes.

F.1 Temperature controls

We start by providing insights on the sensitiveness of the main estimates to the inclusion of temperature controls. In Table 2, we include temperature controls together with other controls not meaningfully affecting our estimates. In Table F4, we further test the effects temperature controls have on the main estimates. To disentangle the effect of temperature and maternal controls, we separately enter maternal controls in columns (2) and (6). We find that maternal controls reduce the coefficients for BW and the low BW classification sightly, without impacting the overall significance of the estimates. However, the inclusion of the temperature controls in columns (3) and (7) reduces only the BW estimates minimally, without any further change on the coefficients for very low and extremely low BW. Furthermore, we show additional robustness to the choice of temperature controls. In columns (4) and (8), we include alternatively maximum daily temperatures as controls rather than average daily temperature. In line with the average temperature controls, we calculate the number of days in bands of 5°C for each pregnancy, starting with the due date and ending with the predicted due date for 280 days of a full-term pregnancy. The inclusion of maximum daily temperature controls leaves the coefficients unchanged, both in terms of magnitude and precision.

Table F4: Effect of Dengue on Birth Outcomes - Additional Temperature Controls

	BW				*Low BW*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dengue	−31.328	−27.413	−27.480	−27.481	0.013	0.011	0.011	0.011
(pregnancy)	(11.416)***	(11.307)**	(11.306)**	(11.306)**	(0.007)*	(0.007)*	(0.007)*	(0.007)*
Mean dep. var.	3,174.865	3,174.865	3,174.865	3,174.865	0.073	0.073	0.073	0.073
Mothers	136,788	136,788	136,788	136,788	136,788	136,788	136,788	136,788
Observations	281,497	281,497	281,497	281,497	281,497	281,497	281,497	281,497
	Very Low BW				*Extremely Low BW*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dengue	0.006	0.006	0.006	0.006	0.004	0.004	0.004	0.004
(pregnancy)	(0.003)**	(0.003)**	(0.003)**	(0.003)**	(0.002)**	(0.002)**	(0.002)**	(0.002)**
Mean dep. var.	0.009	0.009	0.009	0.009	0.003	0.003	0.003	0.003
Mothers	136,788	136,788	136,788	136,788	136,788	136,788	136,788	136,788
Observations	281,497	281,497	281,497	281,497	281,497	281,497	281,497	281,497
Maternal Controls	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Temperature (average) Controls	No	No	Yes	No	No	No	Yes	No
Temperature (maximum) Controls	No	No	No	Yes	No	No	No	Yes

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Robust standard errors are clustered at the mother level in parentheses.

Note: The analysis includes mothers over the period between 2011 and 2017. *BW* is reported in grams. *Low BW*, *Very Low BW* and *Extremely Low BW* are dummies indicating newborns up to 2,500, 1,500 and 1,000 grams, respectively. Explanatory variable *Dengue(pregnancy)* indicates whether the mother had dengue during pregnancy. All regressions include month of conception fixed-effects and maternal fixed-effects. Maternal controls include dummies for maternal age, and dummies for marital status (married, living together, divorced, single, missing), highest education achieved (incomplete primary, complete primary, incomplete secondary, complete secondary, incomplete higher education, complete higher education), occupation codes, number of previous stillbirths, birth order and birth interval (time between conceptions). Temperature (average) controls are variables measuring the number of days during pregnancy with average temperature between 10-15°C, 15-20°C, 20-25°C, 25-30°C and 30-35°C. Temperature (maximum) controls are variables measuring the number of days during pregnancy with maximum temperature between 10-15°C, 15-20°C, 20-25°C, 25-30°C, 30-35°C, 35-40°C and 40-45°C.

F.2 Balancing property of time-varying maternal characteristics and location choice

Our mother fixed-effects estimation strategy deals with any time-invariant maternal characteristics by holding these characteristics constant across the multiple pregnancies observed for the mothers. To also account for remaining time-varying characteristics of the mother and pregnancy that may affect birth outcomes, we add time-varying controls across all estimates, including controls for maternal age, and occupation, and dummies for marital status, highest education achieved, the number of previous stillbirths, birth order, and time between conceptions.[11] To understand whether the time-varying characteristics of mothers are linked to dengue, we test directly whether dengue is related to those characteristics. We provide the results in Table F5 focusing on the time-varying maternal characteristics proxying for socioeconomic status, including maternal age, marital status, education, and occupation. We dichotomize these characteristics for ease of interpretation. Using our preferred specification, including the remaining controls, we find that dengue as a predictor has no effect on those maternal characteristics; the coefficients are small and not statistically significant, providing further credibility to our estimation strategy.

Table F5: Time Varying Maternal Characteristics as Outcomes

	Mother's age			*Mother's marital status*	*Mother's education*	*Mother's occupation*
	20 or less	*21 to 35*	*36 and beyond*	*Married*	*High*	*High-skilled*
Dengue	−0.014	0.016	−0.002	−0.011	0.002	0.017
(pregnancy)	(0.008)	(0.010)	(0.004)	(0.009)	(0.004)	(0.020)
Mean dep. var.	0.255	0.685	0.060	0.558	0.184	0.486
Mothers	136,788	136,788	136,788	134,606	132,957	24,302
Observations	281,497	281,497	281,497	276,934	273,519	49,062

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Robust standard errors are clustered at the mother level in parentheses.

Note: The analysis includes mothers over the period between 2011 and 2017. All regressions include month of conception fixed-effects and maternal fixed-effects and the full set of (remaining) controls (for a detailed list of controls, see Table 2 note).

In addition to time-varying maternal socio-economic characteristics, we also investigate

[11] In detail, we look at the following outcomes: age (20 or less, 21 to 35, 36 and beyond), marital status, high education (where the variable takes a value of 1 for higher education and zero otherwise), high-skilled occupation (with the dummy taking a value of 1 for occupations including high-skilled white collar and high-skilled blue-collar occupations based on the detailed Brazilian Classification of Occupations. We focus on skill levels of occupations based on ISCO-88 definitions by ILO, which we map to the Brazilian occupations).

whether dengue leads to changes in the location of the residence of the mother. In Table F6 we provide the coefficients from of estimates of dengue (during the first pregnancy) on different definitions of 'relocation' outcomes.[12]

Table F6: Effect of Dengue on Relocation

	Relocation 1	*Relocation 2*	*Relocation 3*	*Relocation 4*	*Relocation 5*	*Relocation 6*
	(1)	(2)	(3)	(4)	(5)	(6)
Dengue	0.016	0.005	0.001	−0.001	−0.004	−0.011
(pregnancy)	(0.014)	(0.005)	(0.005)	(0.007)	(0.008)	(0.021)
Mean dep. var.	0.064	0.009	0.007	0.011	0.014	0.279
Mothers	91,436	91,436	91,436	91,436	91,436	91,436
Observations	182,872	182,872	182,872	182,872	182,872	182,872

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Robust standard errors are clustered at the mother level in parentheses.

Note: The analysis includes mothers over the period between 2011 and 2017. All regressions include month of conception fixed-effects and maternal fixed-effects and the full set of controls (for a detailed list of controls, see Table 2 note).

First, in column (1), the outcome variable takes a value of 1 if the mother changes place of residence from one municipality during the first pregnancy to another municipality of residence in the subsequent pregnancy. From column (2) to column (5), we look at selective changes in municipality of residence, with the outcome taking a value of 1 for moving to a relatively richer municipality (where relatively rich municipalities are municipalities with a per-capita income above the median (R$ 466.8)) in column (2), a value of 1 for moving from a municipality with a high share of population with low income to a municipality with a low share of low income individuals (where "high" municipalities have a fraction of individuals with low income greater than the median value 40.75 and "low" municipalities with a fraction smaller than or equal to the median) in column (3), a value of 1 for relocation from an urban to a rural municipality (where we use the official definition of the Brazilian statistical bureau (IBGE) or urban and rural municipalities) in column (4) and a value of 1 for relocation from a municipality with a large population to a municipality with relatively small population (where we consider municipalities with a population of more than 100,000 as "high" population municipalities), and zero otherwise across those definitions. Lastly, as relocation decisions may be more subtle than moving from one municipality to another, we also use as an outcome whether mothers change their neighborhood in response to dengue, providing a

[12]Because we rely on the location information from the birth records (location of residence during pregnancy), we need to restrict the analysis to dengue infections during the first pregnancy, as we do not have information on the residence after the last observed pregnancy in the data.

much more localized relocation variable, particularly for large urban municipalities (column 6). We find that none of the coefficients for relocation are significant, with coefficients being close to zero across the different outcomes, a result that is probably unsurprising given the distribution of dengue across space and time depicted in the maps in Figure A1.

F.3 Timing of dengue infection

In this section, we investigate heterogeneous effects by the timing of dengue infections over multiple pregnancies. For this purpose, we estimate separately the effect of dengue infections in the first pregnancy versus in the last pregnancy in our data. We present the results in Table F7, where in columns (1)-(4) we present the results for first pregnancy infections (and drop observations with dengue infections in subsequent pregnancies) and in columns (6)-(10) for dengue infections during the last observed pregnancy in our sample. We find a moderately larger effect on BW for dengue infections during the first pregnancy compared to the last pregnancy.[13] In contrast, we find a positive effect on the propensity for low BW for infections in the last pregnancy, but not in the first pregnancy, whereas the effects for very and extremely low BW are once more accentuated for infections during first pregnancy, although the estimates are not statistically significant. In contrast, the effects on gestation appear to be slightly more accentuated for infections during the last pregnancy, possibly pointing to some competing mechanism at work here. Splitting the sample by the timing of infections nevertheless reduces the available variation in each exercise, and the coefficients are less precise, with the estimates on very and extremely low BW not being significant. The more pronounced effects for infections during first pregnancy are in line with findings in the medical literature that point to first pregnancies being linked to lower BW.

[13] Although the estimated effect size is smaller for the last pregnancies, these are estimated with more precision. This is due to the fact that we have a larger number of dengue infections in the later pregnancies. We discuss the reasons for this in the data section on dengue.

Table F7: Effect of Dengue on Birth Outcomes by Gestation

Panel A - Birth Weight

	First pregnancy				*Last pregnancy in the data*			
	(1) *BW*	(2) *Low BW*	(3) *Very Low BW*	(4) *Extremely Low BW*	(5) *BW*	(6) *Low BW*	(7) *Very Low BW*	(8) *Extremely Low BW*
Dengue	−38.925	−0.017	0.008	0.007	−29.965	0.019	0.004	0.004
(pregnancy)	(22.816)*	(0.015)	(0.006)	(0.005)	(14.419)**	(0.008)**	(0.004)	(0.002)*
Mean dep. var.	3,174.689	0.073	0.009	0.003	3,174.932	0.073	0.009	0.003
Mothers	135,229	135,229	135,229	135,229	136,024	136,024	136,024	136,024
Observations	278,202	278,202	278,202	278,202	279,849	279,849	279,849	279,849

Panel B - Gestation

	First pregnancy				*Last pregnancy in the data*			
	(1) *Gestation (days)*	(2) *Gestation (<259 days)*	(3) *Gestation (<224 days)*	(4) *Gestation (<196 days)*	(5) *Gestation (days)*	(6) *Gestation (<259 days)*	(7) *Gestation (<224 days)*	(8) *Gestation (<196 days)*
Dengue	0.331	−0.005	0.011	0.005	−0.765	0.010	0.008	0.001
(pregnancy)	(0.865)	(0.017)	(0.009)	(0.004)	(0.510)	(0.010)	(0.004)*	(0.003)
Mean dep. var.	269.849	0.103	0.013	0.003	269.855	0.102	0.012	0.003
Mothers	135,229	135,229	135,229	135,229	136,024	136,024	136,024	136,024
Observations	278,202	278,202	278,202	278,202	279,849	279,849	279,849	279,849

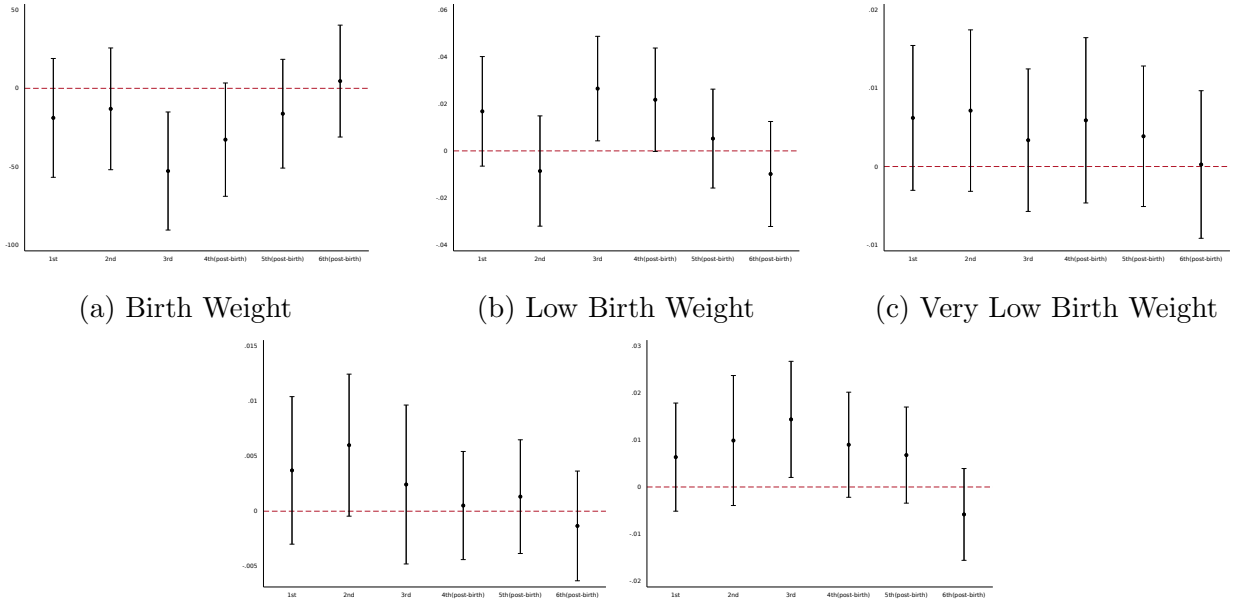
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Robust standard errors are clustered at the mother level in parentheses.

Note: The analysis includes mothers over the period between 2011 and 2017. *First pregnancy* refers to mothers who had dengue in the first pregnancy and *Last pregnancy in the data* refers to mothers who had dengue in the last pregnancy observed in the data. All regressions include month of conception fixed-effects and maternal fixed-effects and the full set of controls (for a detailed list of controls, see Table 2 note).

F.4 Falsification exercise

We also engage in a falsification exercise, using the information on the timing of reported dengue infections. Mechanically, dengue infections after birth cannot affect birth outcomes. We test this by estimating lead variables of infections by trimester using our preferred maternal fixed-effects specification for the significant results of BW, very and extremely low BW, and very preterm birth of Table 2. We display the results in Figure F6, where we plot the point estimates for the three trimesters of pregnancy and three trimesters post-birth.[14] Confirming the results in Table 4, we find a significant decrease in BW for third-trimester infections and smaller negative but insignificant effects for the first and second trimesters, as well as a significant positive effect for very preterm births for third-trimester infections. The graph also displays the coefficient for three trimesters post-birth. As expected, all lead coefficients are small and not significant, lending additional credibility to our identification strategy.

[14] We follow the literature and construct trimesters, during pregnancy and post pregnancy, from conception date irrespective of gestational length (Quintana-Domeque and Ródenas-Serrano (2017). We construct the lead variables in analogue to the trimester variables, based on equal-sized trimesters continuing the trimester variables based on conception date.



(a) Birth Weight (b) Low Birth Weight (c) Very Low Birth Weight

(d) Extremely Low Birth Weight (e) Gestation (< 224 days)

Figure F6: Effect of Dengue on Birth Weight and Very Preterm Birth

Note: We report graphs only for the significant results in Table 2.

F.5 Sensitiveness of effects on hospitalization

In Table F8, we provide the sensitiveness analysis for the significant hospitalization outcomes in analogue to the exercise for the main estimates on BW and gestation for different combinations of fixed-effects and the alternative control group. Across specifications, the coefficients for hospitalization are very stable, but we lose significance when including neighborhood fixed-effects and neighborhood linear trends. This is possibly due to the smaller number of observations when including the neighborhood fixed-effects.[15] In particular, the estimates are very similar when including hospital fixed-effects and hospital linear trends (columns (5) and (6), compared to our benchmark specification. In line with the effects on BW, we also find a slightly accentuated effect for hospitalizations when using the alternative control group. The pattern for hospitalization cost is very similar, with very stable coefficients across specifications and the slightly larger effect when using the alternative control group.

[15] We lose observations as we drop singleton observations in these specifications due to small geographic expansion of neighborhoods with small populations in combination with the mother fixed-effects.

Table F8: Effect of Dengue on Hospitalization - Sensitiveness Analysis

	Hospitalization						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dengue	0.034	0.032	0.027	0.027	0.030	0.029	0.040
(pregnancy)	(0.011)***	(0.013)**	(0.020)	(0.023)	(0.017)*	(0.017)*	(0.017)**
Mean dep. var.	0.117	0.117	0.115	0.115	0.117	0.117	0.145
Clusters	18,303	67,962	9,578	9,578	522	522	2,516
Observations	138,751	138,751	123,428	123,428	138,515	138,515	5,138
R^2	0.029	0.560	0.625	0.696	0.568	0.574	0.611
	Cost						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dengue	0.396	0.366	0.316	0.322	0.339	0.331	0.471
(pregnancy)	(0.125)***	(0.150)**	(0.223)	(0.256)	(0.192)*	(0.194)*	(0.191)**
Mean dep. var.	352.877	352.877	338.974	338.974	352.264	352.264	428.410
Clusters	18,303	67,962	9,578	9,578	522	522	2,516
Observations	138,751	138,751	123,428	123,428	138,515	138,515	5,138
R^2	0.029	0.562	0.626	0.697	0.570	0.575	0.615
Mother FE	No	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	No	Yes	Yes	Yes	Yes	Yes	Yes
Neighborhood FE	No	No	Yes	Yes	No	No	No
Neighborhood Linear Trends	No	No	No	Yes	No	No	No
Hospital FE	No	No	No	No	Yes	Yes	No
Hospital Linear Trends	No	No	No	No	No	Yes	No
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Alternative Control Group	No	No	No	No	No	No	Yes

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Robust standard errors are clustered at the neighborhood level the regressions with neighborhood fixed-effects, at the hospital level for the regressions with hospital fixed-effects and at the mother level for the remaining specifications.

Note: The analysis includes mothers over the period between 2011 and 2017. *Hospitalization* is a dummy indicating whether the infant was hospitalized in the first three years of life. *Cost* is the logarithm of the cost of the hospitalization. Explanatory variable *Dengue(pregnancy)* indicates whether the mother had dengue during pregnancy. For a detailed list of controls, see Table 2 note. *Alternative Control Group* limits the control group to mothers infected with dengue after pregnancy.

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