The Anatomy of a Public Health Crisis: Household Responses Over the Course of the Zika Epidemic in Brazil*

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Abstract

The global frequency and complexity of viral outbreaks is increasing. In 2015, Brazil experienced an epidemic caused by the Zika virus. This represents the first known association between a flavivirus and congenital disease, marking a ‘new chapter in the history of medicine’ [Brito 2015]. We use tens of millions of administrative records to document household responses to a public health alert linking the emerging Zika virus and congenital disease. We find a 7% reduction in pregnancies post-alert, a response triggered immediately after the alert, and driven by higher SES women. On responses during pregnancy, we find an increased use of ultrasounds (9%) and abortions (5%), especially late term abortions. However, these impacts are driven by mothers that conceived post-alert – there is no response to the public health alert during pregnancy among mothers that conceived just pre-alert, despite their unborn children also being at risk. The primary welfare cost of the epidemic is disease avoidance, as households move away from planned fertility paths. We conclude by discussing the extent to which our findings extend to household responses to public health alerts on other emerging viral threats. JEL Classification: I12, J13.

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1 Introduction

Viruses and viral outbreaks have shaped the course of human history. Between 1980 and 2013, there were over 12,000 recorded outbreaks of 215 human infectious diseases, comprising 44 million cases across 219 countries, with the frequency and diversity of viral outbreaks increasing over time [Smith et al. 2014]. The underlying drivers of this have been an increase in the size, density and connectivity of human populations, closer contact between human and animal species, mass displacements arising from conflict, and climate change. The economic costs of outbreaks are severe: even before COVID-19, the annual global cost of moderately severe to severe pandemics was estimated to be 0.7% of global income, greater than the costs of natural disasters, and comparable to those from climate change [World Bank 2017].

As the current COVID-19 pandemic shows, in the short run viral outbreaks can severely restrict economic exchange, alter social interactions and network structures, and raise mortality; while in the long term they can impact morbidity, human capital accumulation and economic growth [Almond 2006, Fogli and Veldkamp 2013]. All these channels of impact stem from increased risk and uncertainty households face during an emerging new viral threat. As such, public health alerts are a vital tool policy makers have in the early stages of epidemics, when behavioral responses of households play a key role in determining the severity of viral outbreaks. In this paper we use tens of millions of detailed administrative records to study multiple dimensions of household behavioral response to public health alerts during a recent viral outbreak: the Zika epidemic in Brazil in 2015.

This particular epidemic is significant because it represents the first ever known association between a flavivirus, carried by the *Aedes Aegypti* mosquito, and congenital disease, representing a ‘new chapter in the history of medicine’ [Brito 2015]. The congenital diseases linked to the Zika virus in the 2015 epidemic included microcephaly: a neurological disorder among newborns in which the occipitofrontal circumference is smaller than that of other children of the same age, race, and sex. It is defined as a head circumference of two standard deviations below the mean for age and sex, or about less than the second percentile [WHO 2014].

The primary vector (carrier) for Zika, the *Aedes Aegypti* mosquito, is familiar to Brazilians because it carrier for viruses including malaria and dengue. These mosquitoes infect two million Brazilians each year, and 300 million globally [WHO 2014]. Work in life sciences to map global

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1Smith et al. [2014] analyze a novel 33-year dataset (1980-2013) collating information on 12,102 outbreaks of 215 human infectious diseases. They examine global temporal trends in the number of outbreaks, disease richness, disease diversity and per capita cases. Bacteria, viruses, zoonotic diseases (originating in animals) and those caused by pathogens transmitted by vector hosts are responsible for the majority of outbreaks. After controlling for disease surveillance, communications, geography and host availability, they find the number and diversity of outbreaks, and richness of causal diseases has increased significantly since 1980.
environmental sustainability for the Zika virus (ZIKV), suggests over 2 billion individuals currently inhabit areas with suitable environmental conditions [Messina et al. 2016].

The timeline of the epidemic was as follows. In March 2015, the WHO received notification from the Brazilian government regarding an illness transmitted by the *Aedes Aegypti* mosquito, but not detected by standard tests. Until early November, it was thus known that Zika was present in Brazil but it was thought to be a ‘dengue-like’ infection, and harmless to newborns. However, on November 11th the Brazilian government issued an alert emphasizing an upsurge in microcephaly in the North East of the country. On November 17th, scientists confirmed the detection of ZIKV in the amniotic fluid of two pregnant women, whose foetuses had microcephaly [PAHO/WHO 2015]. The severity of the epidemic in Brazil deepened, and ZIKV spread rapidly across countries. By February the WHO launched an alert stating microcephaly was an international concern and a pandemic announced. Brazil was the most affected country, with between 440,000 and 1.3 million cases of ZIKV infection through to December 2015 [Mlakar et al. 2016].

We use a difference-in-difference (DD) research design to study impacts on household behavior of the public health alert issued on November 11th. We construct a detailed picture of multiple margins of behavioral response across different household cohorts (before and during pregnancy across stages of the epidemic).

The variation our research design exploits are differences in outcomes between pre- and post-alert periods during the epidemic year when ZIKV was known to be in Brazil, with differences in the same pre- and post-alert periods in pre-epidemic years. This allows us to separately identify the biological and behavioral impacts of Zika. More precisely, differences in behavior pre-alert in the year of the epidemic relative to earlier years identifies the pure biological impact of ZIKV on outcomes when Zika is known to exist but thought to be dengue-like. Differences in behavior post-alert identify the behavioral impact of Zika being known to relate to congenital malformations. Our chief parameter of interest is then the DD between the behavioral and biological effects, that captures the pure impact of the informational alert linking ZIKV to microcephaly.

We conduct our analysis using multiple administrative data sources that provide near universal coverage of birth and hospital care statistics in Brazil from January 2013 onwards. We use birth records covering all 12 million live births in hospitals or homes from January 2013 to December 2017. These detail the exact date and location of birth, demographic characteristics of mothers, and birth outcomes such as birth weight and ICD-10 codes for congenital malformations. The data also records the estimated date of last menstruation, based on medical examinations. We use this to construct an estimated date of conception, and so consider responses among cohorts that choose to conceive pre- and post-alert.
We examine behavioral responses during pregnancy by merging over 400 million inpatient and outpatient administrative records. These cover more than 70% of hospitalizations, including those in all public hospitals and a subset of private hospitals that work with the National Health Service. These record the exact date and hospital of admission, ICD-10 codes are provided for primary and secondary reasons for admission, as well as codes for medical procedures undertaken. We use these records to measure post-alert changes in behavior during pregnancy such as the use of ultrasounds and abortions, as well as the incidence of Zika infection in the population as a whole.

There is currently no vaccine or treatment for ZIKV [Marston et al. 2016]. The only way to guarantee against ZIKV-related birth defects is to avoid becoming pregnant, or to terminate pregnancy. We study both forms of disease avoidance during the epidemic, that represent major welfare costs of the crisis.

Our results on household behavior are as follows. First, we find a significant reduction in conceptions leading to live births post-alert: the magnitude of the effect is 7.21% fewer conceptions per month post-alert. This finding is robust to multiple checks for differential time trends over states and cities, and is precisely estimated: the 95% confidence interval rules out a reduction smaller than 5.7%. This response is also of economic significance, being equivalent to 18,000 fewer children being conceived nationwide each month in the post-alert period, and the response represents 53% of natural variation in conception rates across months of the year due to well known seasonality in pregnancies.

On response dynamics: (i) in the weeks prior to the alert, weekly conception rates were very similar in the year of the epidemic and the year before; (ii) within a week of the alert, a divergence in conception rates opens up. We find significant falls in conception rates for 9 months after the alert, with a return to trend 9 to 12 months post-alert. We however note that the post-alert impact on conception rates never becomes positive and significant: this suggests not just a delay in the timing of pregnancy, but an overall reduction in the number of births.

These reductions reflect women moving away from their unconstrained fertility path, and so can have important consequences for their labor supply, the welfare of other household members, and longer term ability to complete desired levels of total fertility. As in Philipson [2000], we interpret the epidemic as a random ‘tax’ on behavior risking exposure, which thus distorts individuals’ choices by inducing them to forego otherwise valuable activity. This disease avoidance is a first order welfare cost of the epidemic.

The administrative data allows us to precisely identify that the reduction in pregnancies is driven by older and higher SES women. This fits the narrative that higher SES women were either better informed of the risks, or face lower costs of altering fertility timing. We interpret later
outcomes for this cohort as being partly driven by the selected sample of lower SES mothers that
conceive despite the risks highlighted in the official alert. On changes in behavior during pregnancy, we document that among those conceiving post-alert, there are responses during the first trimester of pregnancy such as an increased use of ultrasound (9%). On abortions, despite severe legal restrictions on abortion, officially recorded abortion rates are high pre-epidemic: around 16% of women pregnant in the previous three months have an abortion (partly reflecting the lack of contraceptive access in this context). Our design suggests this rises by a further 5% post-alert (corresponding to around 4,000 more abortions per month post-alert), with a 15% increase in late term abortions.

For ultrasounds and abortions, both DD are driven by changes in behavior during pregnancy of mothers that conceived post-alert, and not because of behavior change among (non-selected) mothers that conceived pre-alert. This lack of response is despite the fact that children conceived pre-alert are obviously still at risk from ZIKV infection. The non-response during pregnancy occurs even among mothers that conceive just prior to the alert, and so have the opportunity to undergo an ultrasound or abortion in the first trimester of pregnancy. This non-response is in line with the kind of limited attention or endogenous belief formation that seems to explain many health behaviors outside of epidemics [Kremer and Glennerster 2012, Dorsey et al. 2013].

On birth outcomes, we document the biological effect of ZIKV increases the incidence of low birth weight children (by 2% of the baseline mean). At the same time we find the DD response to the health alert leads to a significantly lower likelihood to be low birth weight for children conceived post-alert. This is because for children conceived post-alert (i.e. among mothers that did not delay pregnancy) and that reached full term (i.e. among mothers that did not abort), the likelihood of low birth weight also rises relative to pre-epidemic years but by less (1% of the baseline mean). Taking account of post-alert selection of mothers into conception and birth post-alert, we find that the DD impacts on birth outcomes are largely driven by the composition of mothers conceiving and giving birth post alert changing (they are more likely to be teen mothers and with only basic levels of education).

The final set of birth outcomes examined are Zika-specific risks. Here we find a marked rise in cases of microcephaly for children conceived pre-alert (by 1324%). This is the biological effect of Zika on microcephaly. For the selected sample of children conceived post-alert, there is no significant difference in rates of microcephaly relative to children born in similar months in pre-

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2 An older literature has studied household responses to other information to new health risks such as on BSE [Adda 2007], and the false scare over the MMR vaccine [Anderberg et al. 2011]. Adda [2007] shows that responses to new information are non-monotonic in disease susceptibility. Anderberg et al. 2011 find larger responses to the scare (in terms of reduced vaccination rates) among more educated households.
epidemic years. Hence despite post-alert births being concentrated among younger and lower SES mothers, these findings on microcephaly are consistent with these mothers taking offsetting precautions to mitigate the risk of mosquito bites and Zika infection during pregnancy. This suggests that lower SES mothers do have information about Zika risks and are able to act on this information during pregnancy: the costs of preventing mosquito bites during pregnancy are relatively small. In contrast, the earlier results on conception rates suggest the costs of delaying pregnancy altogether are far higher for low SES women, despite them having information about the risks to their newborn.

Our work provides novel contributions to the following strands of literature.

A long-standing literature studies information as an input into health [Viscusi 1990, Cawley and Ruhm 2012]. Given many instances where cost-effective actions to prevent infectious disease, that do not require individual diagnosis, still seem to have limited uptake (such as mosquito nets, vaccinations, water chlorination and deworming), a broad conclusion has been that the mere provision of information might not improve health when other forces are at play such as externalities, credit constraints, present bias and limited attention [Kremer and Glennerster 2012] or the credibility of information [Bennett et al. 2018]. Our findings suggest that exploiting evidence from behavioral interventions that have been shown to impact health behaviors might be especially useful if targeted to groups that do not respond to the public health alert [Haushofer and Metcalf 2020]. In our context this includes women that conceived just prior to the alert.

This micro focused literature differs from the emerging body of work on the economics of epidemics, that represent aggregate health shocks that spread rapidly and cause huge degrees of uncertainty. Economists have built on epidemiological models of disease diffusion, the key insight being that endogenous preventative behaviors in response to viral outbreaks impact the spread of outbreaks, and hence the optimal policy response [Philipson and Posner 1993, Ahituv et al. 1996, Geoffard and Philipson 1996, Kremer 1996, Lakdawalla et al. 2006, Chan et al. 2016]. Such models often suggest preventative responses are triggered when information on the incidence of a (contagious) disease crosses a high threshold [Philipson 2000]. Our results highlight which households undertake such preventative responses, as well as their magnitude and dynamics: these are all key inputs into epidemiological models of viral outbreaks.

Prior to COVID-19, a literature had already begun to study individual behaviors during epidemics such as Agüero and Beleche [2017] on the H1N1 pandemic in Mexico; Backer and Wallinga [2016], Currie et al. [2016], Fluckiger et al. [2018], Maffioli [2018], Bandiera et al. [2019] and Christensen et al. [2019] and on the Ebola epidemic in West Africa; Bennett et al. [2015] on SARS. Evidence remains scarce on the Zika epidemic, and is mostly limited to using household
survey or qualitative data [Diniz et al. 2017, Marteleto et al. 2017, Quintena-Domeque et al. 2017] or descriptive country-level studies in public health that do not aim to disentangle biological and behavioral responses [Aiken et al. 2016, Castro et al. 2018].

Rangel et al. [2020] is the study closest to ours: they use administrative records to estimate the impacts on fertility of the outbreak, and document similar heterogeneous responses across mothers. They do not however examine outcomes beyond fertility, such as changing microcephaly risk across mothers pre- and post-alert, changes in behavior during pregnancy, birth outcomes, and the response of health sector personnel.

Taken together, our results provide a detailed picture of household responses to new information over the course of a rapidly evolving epidemic. As the COVID-19 pandemic shows, in nearly all countries public health alerts are a key policy response at a time of a viral outbreak, whereby households are supplied information by government about which of them are most vulnerable, and behaviors to follow to slow down contagion. Our results provide insights in terms of understanding whether and for how long households respond to public health alerts, which households drive these responses (that is useful for the optimal targeting of information), and margins of response among health care personnel. Our findings strongly suggest responses to health alerts will be heterogeneous across groups, and that two margins of heterogeneity might be especially important for policymakers to consider: (i) those for whom behavioral change is most costly, such as the cost of delaying fertility for low SES women in our study context; (ii) those that entered the risky state pre-alert, who for a variety of reasons might be unwilling to respond to new information despite the fact that they are at risk. It is among this latter group that alternative interventions could be targeted, perhaps leveraging a work using behavioral insights to shift behavior [Haushofer and Metcalf 2020].

A final insight for policy we document at various points of the analysis is that had administrative data been available and analyzed in real time – in relation to doctor’s notes, or microcephaly among newborns – the link between Zika and pregnancy might have been noted some months

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3Diniz et al. [2016] collected survey data in June 2016 from a representative sample of urban women aged 18-39. Marteleto et al. [2017] conducted a qualitative study of responses to Zika, collecting information from focus groups of 6 to 8 women (N = 114) held in the North East and South East during the first 18 months of the epidemic. In all groups, regardless of SES or location, women expressed fear of contracting ZIKV, and the majority of low- and high-SES women mentioned their intention to postpone pregnancy. Quintena-Domeque et al. [2017] surveyed 11,000 women aged 15-49 in the NorthEast between March and June 2016, so well into the epidemic (with a 87% response rate). More educated women were less likely to report having Zika, more likely to report avoiding pregnancy in the last year, more likely to be aware of the association between Zika and microcephaly, and to be taking preventive actions (e.g. wearing light colored clothing, using repellents). In public health, Aiken et al. [2016] compare actual and expected abortion requests by country after the PAHO alert regarding ZIKV (find that the largest discrepancy in rates was in Brazil). Castro et al. [2018] show aggregate time series evidence on how the number of births over the epidemic, with an increase in abortions also noted in aggregate statistics.
prior to official public health alerts being made. We further discuss implications for combining data science and other disciplines in the fight against viral epidemics in the final Section.

The paper is organized as follows. Section 2 provides background to the Zika epidemic in Brazil. Section 3 describes the administrative records and our empirical method. Section 4 presents results on how household behavior responds to the epidemic, sequenced chronologically through pregnancy from conception, behavior during pregnancy, and birth outcomes. Section 5 discusses external validity, and Section 6 concludes with implications for the study of future viral epidemics. The Appendix details our data sources and presents additional results on supply side responses within the health sector over the course of the epidemic as the emerging viral threat became better understood.

2 Zika

2.1 Background

The Zika virus (ZIKV) is a flavivirus carried by the Aedes Aegypti mosquito, that is well-familiar to Brazilians because it is the primary vector for malaria, yellow fever and dengue. Such familiarity no doubt affected how Brazilians initially responded to the virus during the first half of 2015. Prior to the Brazilian epidemic, the known symptoms of ZIKV were a mild fever, skin rash, conjunctivitis, joint pain, headache, erythema and arthralgia. However, ZIKV infection can be asymptomatic among pregnant women [Johansson et al. 2016]. Prior to 2015, known transmission mechanisms were via mosquitoes, sexual intercourse and blood transfusions [Petersen et al. 2016].

The new transmission mechanism identified during the Brazilian epidemic was amniotic fluid: pregnant women could transmit the virus to their fetus [Brito 2015, Brasil et al. 2016]. This represents the first ever known association between a mosquito-borne flavivirus and congenital disease. The most prominent congenital disease recognized during the epidemic was microcephaly.

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4 ZIKV was first identified in 1947 in the Zika Valley, Uganda. Outbreaks have subsequently occurred mostly in Asia and Polynured in French Polynesia, New Caledesia. The main ZIKV epidemic prior to 2015 occia, the Cook Islands, and Easter Island in 2013/4.

5 The last time an infectious pathogen (rubella virus) caused an epidemic of congenital defects was more than 50 years ago. No flavovirus has ever been shown to cause birth defects in humans, and no reports of adverse pregnancy or birth outcomes were noted during previous outbreaks of ZIKV in Polynesia. Two cases of perinatal transmission, occurring around the time of delivery and causing mild disease in newborns had previously been described [Oliveira Melo et al. 2016]. Among flaviviruses, there have only been isolated reports linking West Nile encephalitus virus to fetal brain damage [Oliveira Melo et al. 2016]. On establishing a causal link between ZIKV and congenital defects, Rasmussen et al. [2016] suggest while there is no single piece of definitive evidence establishing a causal link, they build an evidence base using (Shephard’s) seven criteria. This includes that in Brazil, ZIKV was found in the amniotic fluid of two fetuses that were found to have microcephaly, consistent with intrauterine transmission of the virus [Mlakar et al. 2016].
ZIKV infection at any point during pregnancy can impact fetal development. Cauchemez et al. [2016] report the risk of microcephaly is 1% if ZIKV infection occurs during the first trimester of pregnancy. This is low compared to other viral infections associated with birth defects (e.g. it is 13% for cytomegalovirus, and 38-100% for congenital rubella syndrome). However, ZIKV is different because the incidence in the population is very high during epidemics. For example, ZIKV infection rates were estimated to be 66% in the 2013/14 outbreak in French Polynesia. Hence although ZIKV is associated with low fetal risk, it remains a major public health issue and can cause large abrupt changes in fertility related behaviors.

2.2 Timeline

In March 2015, the WHO received notification from the Brazilian government regarding an illness transmitted by the *Aedes Aegypti* mosquito, but not detected by standard tests. On October 16th the WHO issued a communique stating that discussions with Brazilian public health authorities had confirmed the autochthonous transmission of ZIKV in North East of the country. The communique emphasized using surveillance to determine if ZIKV had spread to other areas, and to monitor for neurological and autoimmune complications. There was no mention of threats to those in utero. Hence until early November, the common perception among the public and health care personnel was that Zika was a ‘dengue-like’ infection, and harmless to newborns. The period from May to October 2015 thus marks the pre-alert period for our empirical analysis.

However, on November 11th, the Brazilian government issued a widespread and official alert emphasizing an upsurge in microcephaly in the North East, acknowledging the region as the epicenter of the epidemic, with the state of Pernambuco mentioned. This was the first time a potential connection between ZIKV and microcephaly was made. The report received major media coverage: the *Jornal Nacional* TV news network, that reaches 110 million individuals, broadcast the alert nationwide on the same day. November 2015 marks the start of the post-alert period for our analysis.

Brazilian authorities recommended pregnant women take precautions to avoid mosquito bites, and to use contraceptive methods to postpone or delay pregnancies. Health authorities recommended increasing access to contraceptives in the public health system, and to strengthen coun-

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6 The origins of the ZIKV virus in Brazil are thought to be the Va’a World Sprint Championship canoe race, held in Rio in August 2014, that included athletes from French Polynesia, New Caledonia, the Cook Islands and Easter Island – all countries with a high incidence of ZIKV at the time [Triunfo 2016].

7 On November 17th, scientists confirmed the detection of ZIKV in the amniotic fluid of two pregnant women, whose foetuses had microcephaly [PAHO/WHO 2015]. A WHO communique that day made explicit mention of microcephaly and a potential link to ZIKV (that was not claimed as causal). The communique recommended analyzing live birth databases for malformations/neurological disorders.
scling to inform women who wanted to get pregnant about cases of microcephaly. Our records allow us to check for whether such behavioral responses occurred among health personnel.\(^8\)

ZIKV spread rapidly across countries. On February 1st 2016, the WHO launched an alert stating microcephaly was an international concern. Brazil was the most affected country, with more cases than the rest of Latin America combined. Estimates suggest between 440,000 and 1.3 million cases of ZIKV infection were reported through to December 2015 (among all individuals, irrespective of gender or whether pregnant) [Mlakar et al. 2016].

3 Data, Descriptives and Empirical Method

3.1 Administrative Records

Our analysis exploits multiple administrative data sources, providing near universal coverage of birth and hospital care statistics from all 27 states and 5565 cities (municipalities) in Brazil from January 2013 onwards. We present their key aspects below, with further description in the Data Appendix.

The analysis of pregnancy and birth outcomes is based on 12 million live birth records (\textit{SINASC}), covering all live births in public and private hospitals, and in homes, from January 2013 to December 2017. \textit{SINASC} records the exact date of birth, location of birth (city and hospital), city of residence of mother, demographic characteristics of mothers, and father’s age. The data also records the estimated date of last menstruation, based on medical information obtained from doctors using a physical examination or other method. From this we construct an estimated date of conception. Birth outcomes recorded include delivery method, birth weight, gender, and the number of prenatal visits. Finally, \textit{SINASC} contains ICD-10 codes for any congenital malformation that we use to measure the incidence of microcephaly among newborns.\(^9\)

\(^8\)Through November, 130,000 Brazilian households undertook screening, and 220,000 soldiers were sent to patrol 300 cities in the North East to combat mosquito nests and advise households on the risk of stagnant water close to homes. 71,000 soldiers were sent to Rio because of the Olympic Games being hosted there in 2016.

\(^9\)When the estimated conception date was missing, we recovered it using information on the estimated pregnancy length. On the demographic characteristics of mothers, race categories are white and non-white. Education categories are basic, high school and diploma or more (that we use to proxy SES status). Marital status is single or married. APGAR scores are provided after one and five minutes: these measure the physical condition of newborns, obtained by adding points for heart rate, respiratory effort, muscle tone, response to stimulation, and skin coloration (the highest score is 10). These codes for thus follow the International Statistical Classification of Diseases and Related Health Problems 10th Revision, or ICD-10, created by the World Health Organization. ICD-10 codes do not change during the sample period. However, the definition used by the Brazilian government to diagnose microcephaly changed twice post-alert. The first time was on 4th December 2015 when the Ministry of Health redefined microcephaly as births with cephalic perimeter of 32 cm or lower (prior to this it was officially defined as 33 cm). The second change occurred on the 18th November 2016 when the criteria became 30.5 cm for boys and 30.2 cm for girls. Given our results on microcephaly are based on unchanged ICD-10 codes, none of our results are impacted by these definitional changes of the Brazilian government, further details of which can be found
Our working sample of birth records covers women aged 12 to 49 with no missing data on estimated conception dates: we thus use 11,769,217 birth records from January 2013 to December 2017, so covering conception dates from March 2012 to February 2017. This gives an approximate baseline mean of 250,000 conceptions per month.

As SINASC does not contain unique identifiers for women, we cannot link across pregnancies. We thus aggregate the data to the city-month level (cm), where we have 267,120 = (5565 cities × 48 months) city-month observations. We define a city-month conception rate \( \frac{\text{Number of pregnancies}}{\text{Number of women}_{c,2012}} \times 1000 \). To measure the number of women aged 12 to 49 in city \( c \) in 2012, we use the DATASUS data that predicts city populations by subgroup for 2012 based on the 2010 census. We later also define conception rates within subgroups to examine heterogenous responses to the epidemic alert across women.

To examine behavioral responses during pregnancy we merge 400 million inpatient and outpatient administrative records (SIH and SIA). These data covers all public hospitals and a subset of private hospitals that work with the National Health Service, covering more than 70% of hospitalizations. These record the date of admission, hospital of admission and city of residence of the mother. ICD-10 codes are provided for primary and secondary reasons for admission (where the treating doctor determines the diagnosis). Unique codes are provided for each medical procedure undertaken, with separate codes for primary and secondary medical procedures. Our working sample is constructed from inpatient-outpatient records from January 2013 to June 2017. As with the SINASC records, we aggregate the data to the city-month level (cm), where we have 300,510 = (5565 cities × 54 months) city-month observations.

We use the inpatient-outpatient records to measure post-alert changes in behavior during pregnancy such as the use of ultrasounds and abortions. These data also allow us to measure risks of Zika infection, and the behaviors of health service personnel, such as the use of tests for dengue, and counseling on contraceptive use.

Beyond its scale and detail, there are two other central advantages of using administrative data over household survey data that much of the earlier literature has used to study responses to epidemics. Using diagnosis reports based on trained professionals reduces recall bias and other measurement errors in self-reported survey data. It also mitigates concerns over experimenter demand effects: for example, Zwane et al. [2011] suggest that the mere act of surveying people can change their behavior, consistent with models of limited attention, that have been found to be important for understanding health behaviors [Kremer and Glennerster 2012].

3.2 Descriptives

3.2.1 Microcephaly and Dengue

The clearest marker of the severity of the epidemic is the incidence of microcephaly. Figure 1A shows the time series of microcephaly cases among newborns, by region, as reported in administrative birth records. Pre-epidemic, the number of cases is essentially zero in all regions. There is a rapid rise in cases from the third quarter of 2015 (so among newborns that would have been conceived in early 2015). The incidence of microcephaly peaks around December 2015 and then diminishes steadily by the end of 2016, but the series does not converge to pre-epidemic levels in most regions. Over the pre-alert period from May to October 2015, when ZIKV was known to exist in Brazil, but thought to have dengue-like symptoms, there were 395 cases of microcephaly in total. In the post-alert period, from November 2015 to April 2016 there were a further 2522 cases throughout Brazil.

The North East was clearly the mostly affected region: at the peak of crisis, it had almost 10 times the number of microcephaly cases as the next most affected region (the South East). Figure 1B shows the spatial variation in microcephaly. While this again highlights the North East as the most affected region, it also shows the considerable variation in incidence within regions.\(^\text{10}\)

As highlighted in Figure A1, these temporal and spatial patterns are very different to those for dengue, that is a long-standing (urban) disease also carried by the \textit{Aedes Aegypti} mosquito.\(^\text{11}\)

3.2.2 Public Awareness

While the public health alert was immediately broadcast on TV media, full public awareness of the epidemic might have taken time to rise. We present evidence using online archives of three leading national newspapers: \textit{Folha de Sao Paulo}, \textit{Estadao} and \textit{O Globo} (these archives cover

\(^{10}\)This geographic variation is in line with existing work using spatiotemporal models to simulate the spread of other viral epidemics. For example for the Ebola epidemic in West Africa in 2014-6, a body of work suggests the geographic incidence was largely uncorrelated to economic, social or political characteristics of locations [Backer and Wallinga 2016, Maffioli 2017, Fluckinger \textit{et al.} 2018]. However, recent work has suggested the prevalence of microcephaly varies across ZIKV endemic regions because of a relationship between undernutrition and microcephaly [Barbeito-Andres \textit{et al.} 2020]. The mechanism proposed is that malnutrition causes immunodeficiency and can increase a host’s susceptibility to infection and amplify pathogenesis severity. An alternative channel proposed to explain variation in microphaly due to ZIKV include the quality of drinking water [Pedrosa \textit{et al.} 2019].

\(^{11}\)There are two obvious differences between the incidence of dengue and ZIKV. First, the prevalence of dengue increases around the rainy season, while the ZIKV outbreak occurred over summer. Panel A of Figure A1 confirms this using administrative records on the number of dengue cases by quarter. Second, dengue is concentrated in the South East and Centre West (as shown in Panel B of Figure A1), while Zika was concentrated in the North East. However, pre-alert, many individuals might have thought the new virus to be dengue-like. Panel C of Figure A1 shows the time series in \textit{Google} searches for ‘dengue’ in Brazil (where the y-axis is a \textit{Google}-provided measure of search intensity), and this follows the seasonal variation in actual dengue cases shown in Panel A. Panel D confirms that more \textit{Google} searches are typically made in the South East where dengue is more prevalent.
both online and national editions of each newspaper, and we exclude regional printed editions). In each archive, we searched for ‘microcephaly’. Figure 2A shows the resulting time series of media coverage: we see little evidence of microcephaly having been mentioned pre-alert, and a large spike in reporting, starting on the day of the alert and running until the middle of 2016.\(^\text{12}\)

Figure 2B shows the time series of Google searches for Zika, microcephaly (in Portuguese) or repellent (where the y-axis is a Google-provided measure of search intensity). This shows there was some public awareness of Zika and microcephaly pre-alert, spikes in awareness post-alert, with the spatial pattern of searches being more widespread (as shown in Panel C), and not concentrated either in the North East (where the majority of microcephaly cases occurred) or in the South East (where dengue was most prevalent).\(^\text{13}\)

### 3.2.3 Doctor Awareness

We use the national system of notifiable diseases (SINAN) to measure doctors’ awareness of Zika. This database details individual doctor-patient meetings in all hospitals where patients report symptoms of dengue. Details on doctor’s notes are available from January 2014 until January 2016 (so just two months post-alert), covering 3.2 million patient samples.

Panel A in Figure 3 shows the time series of microcephaly being recorded in doctors’ notes from these meetings (per 1000 dengue cases). Other causes of microcephaly apart from ZIKV include cytomegalovirus, herpes simplex virus, rubella virus, and *Toxoplasma gondii*. All existed in Brazil pre-epidemic, so microcephaly due to ZIKV could easily be missed or misdiagnosed [Petersen *et al.* 2016]. There is however a clear jump up in microcephaly being written in doctor’s notes post-alert.

Panel B shows mentions of Zika in doctor’s notes. There is an increase in mentions from April 2015 onwards, with such observations increasing dramatically post alert. The Ministry of Health made Zika-related notifications compulsory from February 2016. This rapid rise mirrors the earlier

\(^\text{12}\)Ribiero *et al.* [2018] present qualitative evidence on the media coverage of Zika in two of these newspapers: *O Globo* and *Folha de São Paulo*. They analyze 186 articles published between December 2015 and May 2016, and argue that this reveals a dominant ‘war’ frame of articles related to Zika, that are underpinned by two sub-frames: one focused on eradicating mosquitoes, and one focused on controlling microcephaly, but placing the burden of prevention on women. Women (especially pregnant women) became the main target audience, where they “should receive orientation about how to have safe sex,” [*O Globo*, 9 March 2016], to avoid microcephaly. Women were this framed as both victims of Zika, but also as those responsible for taking decisions on pregnancy. They suggest the prevailing framing of Zika often failed to highlight the importance of social factors or differences in exposure across the SES gradient. The Zika outbreak also coincided with political instability and the Rio Olympics. Partly as a result, debate became politicized as reports on the spread of Zika merged political concerns over the former president’s wrongdoing.

\(^\text{13}\)All of this is consistent with small-scale qualitative studies conducted during the crisis, such as Marteleto *et al.* [2017] and Quintena-Domeque *et al.* [2017] that suggested women expressed a desire to avoid pregnancy, and that the main reason for doing so was to avoid the possibility of becoming infected during pregnancy and transmitting the virus to the developing fetus.
Finally, Panel C shows that among patients reporting dengue-like symptoms, there was increased attention to pregnant women pre-alert (that is noticeably higher compared to a year earlier). This increase occurs before the formal alert was issued in November 2015. It suggests that had such administrative data been available and analyzed in real time, the link between Zika and pregnancy might have been noted earlier.

### 3.3 Empirical Design

We divide the epidemic period into: (i) the pre-alert period between May and October 2015, when it was known that ZIKV was in Brazil, but its symptoms were thought to be dengue-like and so with little consequence for those in utero; (ii) following the official alert on November 11th 2015, the post-alert period covers November 2015 through to April 2016, when the association between ZIKV and congenital disease became known. For each six month period we have corresponding control periods from the two earlier years of administrative records that we exploit to assess the common trends assumption. We estimate the following difference-in-difference specification for outcome $y$ in city-of-residence $c$ in month $m$ in period $t$:

$$y_{cmt} = \alpha_c + \alpha_m + \beta_1 [PRE-ALERT_m \times Zika_t] + \beta_2 [POST-ALERT_m \times Zika_t] + \gamma X_{ct} + \varepsilon_{cmt}, \quad (1)$$

where $y_{cmt}$ corresponds to the conception rate as defined earlier, and $Zika_t$ is a dummy equal to one over the epidemic, so from May 2015 to April 2016, and zero otherwise. $PRE-ALERT_m$ is a dummy equal to one from May to October for years 2013 to 2015, and $POST-ALERT_m$ is a dummy equal to one from November to April for years 2013/14 to 2015/16.

$\alpha_m$ are month fixed effects capturing seasonal variation in pregnancies. $\alpha_c$ are city fixed effects capturing fixed differences across cities. The time varying covariates $X_{ct}$ include climate related controls to help capture conditions conducive to mosquito prevalence.$^{14}$ $\varepsilon_{cmt}$ is an error term clustered by state, to allow for contemporaneous spatially correlated shocks to conception rates. To recover impacts on a representative woman, observations are weighted by the 2012 population

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$^{14}$ Temperature controls are derived from data from the National Institutuer of Meteorology (INMET). This data is collected from 254 stations across Brazil. Most stations provide daily updates on minimum temperature, average temperature, maximum temperature (all in Celsius), wind speed, total insolation, precipitation, and air humidity. To generate city-month climate variables we proceed as follows. First, we use latitudes and longitude information on each station, provided by INMET. To then measure weather variables for each city, we use the latitudes and longitudes of each city, available from the Brazilian Institute of Geography and Economics, to identify the three nearest stations for each city. We do so using geodetic distances based on the shortest curve between two points, accounting for the curvature of the Earth. Once the three nearest stations are identified for each city, we use a weighted average of the three nearest stations for each weather variable. We consider as weights the inverse of the distance between the city and the station.
share of women aged 12-49 in city $c$.

$\beta_1$ captures the difference in conception rates from May to October 2015 and corresponding months in earlier years. Following Rangel et al. [2020], we label this a ‘biological’ effect, as it captures the pure impact of Zika (and any behavioral response driven by a desire to avoid Zika for its perceived dengue-like symptoms). $\beta_2$ captures the difference in conception rates from November 2015 to April 2016 and corresponding months in earlier years: this estimates the impact of Zika being present but also known to relate to congenital malformations such as microcephaly. We label this a ‘behavioral’ effect.

The key difference-in-difference is $\beta_2 - \beta_1$, capturing the pure impact of the informational alert linking ZIKV to microcephaly. This is our chief parameter of interest.

The main identifying assumption is that conception rates in the pre- and post alert periods in the Zika epidemic period would have followed pre-existing trends in the counterfactual of no epidemic. In support of this, we present a battery of robustness checks allowing for state or city specific time trends into the epidemic period.

Conceptions (that led to births) are the first outcome we consider and they represent an important adjustment margin as individuals decide to diverge from their planned fertility path. This can have important consequences for women’s labor supply, the welfare of other household members, and their ability to complete desired levels of total fertility.

Panel A of Table 1 presents descriptive evidence on conception rates, by time period. We see that: (i) in the control pre-epidemic years, conception rates are higher between May and October than between November and April ($4.24 \text{ vs. } 3.91$); (ii) during the first half of the epidemic pre-alert, conception rates are no different in 2015 than earlier years ($4.24 \text{ vs. } 4.19$); (iii) conception rates fall further during the epidemic post-alert than similar months in earlier years ($3.57 \text{ vs. } 3.91$); (iv) the difference-in-difference in conception rates is negative and significant ($-0.296, p = .000$), corresponding to an 8% fall in conception rates relative to November-April months pre-epidemic.

4 Household Responses to the Epidemic

4.1 Conception Rates

Table 2 shows regression estimates of how conception rates respond to the public health alert linking ZIKV and microcephaly. The foot of each Column reports the key difference-in-difference (DD) with its associated 95% confidence interval. To benchmark magnitudes, we show the baseline mean of the outcome variable (the May to October period in pre-epidemic years), and the percentage impact the DD estimate corresponds to in parentheses.
Columns 1 and 2 control for city and month fixed effects respectively; Column 3 controls for both. Column 4 estimates (1) in full and represents our baseline estimates. We find that: (i) $\hat{\beta}_1$ is not statistically different from zero, so that pre-alert, the biological effect related to the known presence of Zika in itself does not change conception rates relative to earlier years; (ii) $\hat{\beta}_2 = -0.319$ and this is statistically different from zero ($p = .000$), so that post-alert, there is large behavioral response in conception rates; (iii) the DD is $\hat{\beta}_2 - \hat{\beta}_1 = -0.306$, that is statistically different from zero ($p = .000$). This isolates the causal impact on conception rates due to the public health alert linking ZIKV and microcephaly.

The magnitude of effect corresponds to a 7.21% reduction in conception rates, that is precisely estimated: from the 95% confidence interval, we can rule out a reduction smaller than $-0.241$ (5.7%). This is of economic significance: the response is equivalent to 18,000 fewer children being conceived nationwide each month in the post alert period. An alternative benchmark is the natural seasonal variation in conception rates. The difference between the largest and smallest month fixed effects ($\alpha_m$) is $\alpha_{August} - \alpha_{February} = 0.582$. Hence the response to the alert represents 53% of the natural fluctuation in conception rates across months of the year.

This reduction in conception rates is derived from birth records: hence it corresponds to households deciding to delay conceptions that would otherwise have led to a live birth. We later document changes in behavior during pregnancies, including the increased use of abortions that further reduces birth cohort sizes.

The administrative records cover all births: those in public hospitals, private hospitals and at home. Hence the fall in conception rates could be driven by individuals avoiding hospitals post-alert. Indeed, a common thread in the economics literature is that in epidemics with high degree of human-to-human contagion (such as SARS, H1N1 or Ebola), the fear of contagion can cause individuals to avoid health care services altogether or lose trust in the health care system [Bennett et al. 2015, Evans et al. 2015, Christensen et al. 2019]. Such prevalence responses can significantly worsen outbreaks. However, such avoidance behaviors are less likely to occur for Zika because the dominant transmission channel is via mosquitoes, not contagion from others.\textsuperscript{15}

Nevertheless, to check for this, in Table A1 we use the linked inpatient-outpatient records to estimate how hospital admissions change over the epidemic (as constructed from over one billion patient admission episodes and then aggregated to the city-period level). This shows no change

\textsuperscript{15}Evans et al. [2015] document how during the 2014-6 Ebola epidemic in West Africa, deaths were disproportionately concentrated among health personnel. This led to a rapid loss of trust and usage of hospitals. Bennett et al. [2015] show that during the 2003 SARS epidemic in Taiwan outpatient visits fell by more than 30 percent in a few weeks, in response to public information and multiplier effects of social interactions. Christensen et al. [2019] document how primary health clinics that have established greater trust with patients prior to the Ebola epidemic in Sierra Leone were able to maintain better rates of functioning during the crisis.
in admission rates among the general population (Column 1), even allowing for state specific time trends (Column 2). Narrowing in on hospital admission rates for pregnant women, we see the fall in admission rates is 6.91%, that closely matches the estimated fall in conception rates (Column 3) and this remains so when we allow for state specific time trends (Column 4). These results confirm households do not avoid using hospitals during the Zika epidemic.

Two implications follow from the pattern of biological and behavioral effects estimated in Table 2. First, the cohort of children conceived during the pre-alert stage of the epidemic would obviously still have been at risk if their mothers became infected with Zika. We trace their outcomes below, and interpret them as being representative of pregnancies that normally take place in the pre-alert months each year (as the biological effect \( \hat{\beta}_1 \) is a precisely measured zero). Second, in contrast, the cohort of children conceived post-alert are selected (as \( \hat{\beta}_2 < 0 \)). We interpret later outcomes for this cohort as being partly driven by the selection of mothers that choose to conceive despite the risks highlighted in the alert.

The remaining Columns in Table 2 probe further the common trends assumption underlying the research design. The specification in Column 5 allows for state-specific linear time trends in conception rates (\( t\alpha_s \)): the resulting DD estimate is hardly unchanged at \(-.305\), corresponding to a 7.2% reduction in conception rates. Column 6 shows the results to remain robust to allowing for state-specific quadratic time trends (so including \( t\alpha_s \) and \( t^2\alpha_s \)), and Column 7 shows the DD estimate remains unchanged allowing for city-specific time trends (\( t\alpha_c \)). The fact that the core estimate is robust in magnitude and significance to these alternative time trends is unsurprising given the unanticipated, severe and rapid diffusion of the epidemic. These various checks for trends helps rule out the concern that slow-changing macroeconomic conditions impacted fertility during the epidemic year [Castro et al. 2018].

Column 8 allows the post-alert impacts to vary by region, where the South is the reference category. There are significant reductions in conception rates across all regions, with the largest impact being in the North East, followed by the Centre West and South East. Reassuringly, this replicates the ranking across states in the time series on microcephaly shown in Figure 1A.16

Table A2 presents a battery of further checks. For ease of comparison, Column 1 repeats the baseline specification from Column 4 in Table 2. The remaining Columns show this result to be robust to: (i) dropping month fixed effects and then controlling for \( PRE-\text{ALERT}_m \) and \( POST-\text{ALERT}_m \),

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16The magnitude of the response in the North East is very similar to that implied by survey evidence collected from women survey in the North East during the outbreak. For example, among the 11,000 women aged 15-49 surveyed in that region between March and June 2016, Quintena-Domeque et al. [2017] find that 51% of them report having used contraceptives (or abstinence) to delay or avoid getting pregnant in the last 12 months. Among this 51%, 18% reported this behavior to be motivated by Zika, corresponding to a \(.51 \times .18 = 9\%\) response overall. Our DD design implies a 10% reduction in conception rates in that region.
$ALERT_m$ directly (Column 2); (ii) not weighting observations: suggesting the results are not driven by large cities (Column 3); (iii) dropping smaller cities that ever had zero pregnancies in a month over the sample: suggesting the findings are not driven by small cities (Column 4); (iv) including additional birth records data from 2012 (that were originally dropped because of conception dates being less reliably recorded in that year) (Column 5); (v) using an alternative numerator to calculate conception rates that accounts for women currently pregnant for observation $t$ in city $c$ and so not at risk of conceiving (Column 6).

Column 7 examines robustness controlling for policy responses. In particular, we use the CNES administrative data, that provides detailed information on the main specialization of all health workers at a municipal level, to construct and then control for panel data in each city/municipality on the number of health workers assigned to combat the epidemic, those assigned for sanitary visits, as well as the total number of professionals in the National Health System and working in private hospitals. We see that the coefficients of interest on the biological and behavioral effects are almost unchanged from our baseline specification.

A final concern is that the epidemic caused women to migrate to different cities to give birth, changing the underlying composition of those giving birth in city $c$. We check for this in Column 8 of Table A2 where the outcome is the share of women giving birth in the city-period whose city of residence and city of birth differ. We see the DD on this is zero and precisely estimated. The evidence strongly suggests the alert did not cause women to migrate across cities to give birth. We probe this further by focusing in on those cities where abortions or ultrasound are offered by hospitals. Neither service is universally offered in Brazil: 31% of cities provide abortions and ultrasound, 45% provide neither, 15% provide only abortions, and 9% offer only ultrasound. The set of cities with the technology and infrastructure to offer these services are the largest ones: so around 80% of all women have access to both services, and this set of cities does not change over the epidemic. Columns 9 and 10 show that post-alert, pregnant women are far less likely to move across cities to give birth if they reside in a city that offers abortion or ultrasound services. The lack of migratory response is in line with what is reported Rangel et al. [2020].

\footnote{In particular, it subtracts from the number of women in the city the number of women that started their pregnancies in last 8 months (i.e. $t, t - 1, \ldots, t - 8$), and the number of women giving birth during months $t, t - 1, \ldots, t - 8$.}

\footnote{Cities that offer abortion or ultrasound services are likely to be in wealthier areas: they are in cities that are larger, have a higher share of mothers with a diploma, fewer teenage mothers, a greater share of White mothers, and are more concentrated in the South East region.}

\footnote{We have also considered migration out of areas based on their risk as defined by the number of Zika cases over three periods (pre-alert, post-alert and through the year of the Zika epidemic). Low risk areas are defined as having no Zika cases in the relevant period. We find migration rates are mostly time invariant and explained by city/municipality fixed effects. Over and above this we see evidence for a small reduction in migration rates out of higher risk areas (counter to the notion of migration as a compensatory response).}
These findings on the behavioral response to the health alert have important implications for the wider literature in health. First, it is often found that individuals are willing to spend more on treatment than prevention, holding cost effectiveness constant [Kremer and Glennerster 2012]. Often the preventative behaviors in question are those that would benefit children (such as vaccination), suggesting household decision making places low weight on child health, or that present biases or limited attention prevent such actions being taken. This is not the case for the public health warning during the Zika epidemic: the sizeable reduction in conception rates implies many households are willing to take action to avoid exposure to the risk of the virus altogether, a risk that predominantly intergenerationally transmits to unborn children. As in Philipson [2000], we thus interpret the epidemic as a random ‘tax’ on behavior which risks exposure, so distorting individuals’ choices by inducing them to forego that otherwise valuable activity.

4.2 Dynamic Responses

Responses to the health alert might not be immediate if it takes time for the information to spread, or for individuals to become convinced of the risk. We use two approaches to understanding dynamic responses. First, the birth records actually provide an estimated week of conception. To examine short run dynamic responses to the alert we therefore show weekly conception rates in the period around the alert and compare those to conception rates from the same week in the year before. This evidence is in Panel A of Figure 4, and although the weekly estimates are noisy, we see: (i) in the weeks prior to the alert, weekly conception rates were very similar in the year of the ZIKV epidemic and the year before (so no evidence of pre-trends); (ii) immediately after the alert – within a week – a divergence in conception rates opens up. The immediacy of the response helps rule out other concerns, such as slow-changing macroeconomic conditions during the epidemic year, as impacting fertility.

Point (i) has significance beyond ruling out pre-trends. As conception rates are derived from birth records, had we found a decline in conception rates (that ended in a live birth) just prior to the alert, that would have suggested the possibility that some conceptions – that still in their first trimester post-alert – actually ended in abortion (and would not therefore have been picked up in birth records). The evidence in Figure 4A suggests this is not the case: conception rates are near identical pre-alert across years. We later examine behavior during pregnancy in more detail, including the incidence of abortions. Those results will be in line with the evidence in Figure 4A, that those conceiving pre-alert are not more likely to abort, even though their child is at risk and they have time to abort post-alert.

Our second approach to dynamic responses extends the monthly sample into the post-alert
period to conceptions up to February 2017 and estimates the following specification:

\[
y_{cnt} = \alpha_m + \alpha_c + \sum_t \beta_3 \text{Alerttime}_t + \gamma X_{ct} + \varepsilon_{cnt},
\]

where \(\text{Alerttime}_t\) is the number of months since the official alert publicly linking Zika and microcephaly. \(\text{Alerttime}_t\) is defined to be zero in November 2015 and we allow it to run from \(-6\) to \(+15\) (where negative values thus shed light on the dynamics of \(\beta_1\) from (1)). We define conception rates in logs so that we can more easily compare percentage impacts across time.

Panel B shows the sequence of \(\tilde{\beta}_3\)'s from (2). There is again no evidence of differential trends pre-alert. There are however significant falls in conception rates for 9 months post-alert. Conception rates fall the month before the official alert: this effect is driven by households in the South East, where dengue is most prevalent and households have the best access to contraception. Focusing on dynamic responses in the North East, the sequence of \(\tilde{\beta}_3\)'s is shown in Panel C: here we see no change in conception rates pre-alert, the trough occurs some three months post-alert, suggesting it takes time for the alert to fully be responded to. Conception rates return to trend 9 to 12 months post-alert. Conception rates thus return to trend while microcephaly cases remain above their pre-epidemic levels, as shown in Figure 1.\(^{20}\)

We however note that the post-alert impacts never become positive and significant: this suggests not just a delay in the timing of pregnancy, but an overall reduction in the number of births in the study period. However, this period is too recent to say anything about lifetime impacts on total fertility. We return to this issue below when we examine heterogeneous responses to the alert, including for older women for whom any reduction in conception rates is more likely to translate to lower lifetime fertility.

### 4.3 Heterogeneous Responses

The near universal coverage of the administrative birth records allow us to precisely establish heterogenous responses to the alert across subgroups of mothers. Heterogeneous responses can be driven by variation in information, risks and costs of delaying pregnancy. For each subgroup, we estimate a specification analogous to (1), but define conception rates in logs to directly compare percentage impacts across subgroups. Figure 5 plots \(\tilde{\beta}_2 - \tilde{\beta}_1\) for each subgroup, and its associated 90% confidence interval.

\(^{20}\)These dynamic responses are shorter-lived than suggested by qualitative evidence collected from mothers during the epidemic. As reported in Marteletto et al. [2017], when discussing how long women intended to postpone pregnancy because of ZIKV, responses varied from specific periods, like 2 or 3 years, to more abstract answers, such as, “when they find a cure,” “when they create a vaccine,” or “until doctors learn more about the epidemic and the mechanisms by which it affects the baby.”
The results show that: (i) there are few significant differences in response based on race (white versus non-white) or marital status (single versus married); (ii) there is a strong gradient between conception rate responses and education: mothers with low education (up to 7 years) respond less than mothers with high-school (8 to 11 years), who in turn respond less than mothers with a diploma (12 or more years); (iii) there is a U-shaped gradient between conception rate responses and age: mothers in their 30s respond most to the alert: the weaker response among older women can reflect the cost of delaying pregnancy being higher for them, all else equal. However, we note that even among the oldest cohort of women – who are likely to be close to the end of their fertility cycle – there is a significant reduction in conception rates by nearly 8%.

We combine information on age and education to define young/old cohorts (where young mothers are aged 12 to 34), and high/low SES mothers (where high SES mothers are those with high school or diploma educations). We see that in each age cohort, higher SES mothers have larger reductions in conception rates.\textsuperscript{21}

The documented heterogeneity in responses fits the narrative that higher SES women were better informed of the risks, or face lower costs of altering their fertility timing (say because they have more bargaining power within marriage or are more patient), and so delayed pregnancy in response to the information alert. An implication is that the cohort of children that are conceived post-alert are selected, being more likely to be born to younger and lower SES mothers relative to the pre-alert period in the counterfactual no epidemic scenario. We thus interpret later outcomes for this cohort as being partly driven by this selection of lower SES mothers that choose to conceive despite the risks highlighted in the official alert.

To tease apart these competing explanations of what drives heterogenous responses across women, we use ICD-10 codes at birth from the birth records to calculate relative risk ratios for microcephaly for each subgroup of women (namely the share of newborns with microcephaly with mothers in group $g$, divided by the share of all mothers in group $g$). We do so for the same subgroups as considered in the analysis of heterogeneous responses in conception rates in Figure 5, and do so separately for the pre- and post-alert periods.

Figure 6 shows the results. We see that pre-alert, risk ratios differ markedly from one across subgroups. For example, pre-alert, white mothers face lower risk than non-white mothers, married women face lower risk than singles, risks fall with education levels and age. These differences reflect differences in exposure to mosquitoes as well as preventative behaviors against bites.

Strikingly, post-alert the risk ratios across groups all converge towards one. This equalization of

\textsuperscript{21}These results are supported by Rangel et al. [2020], who also document larger responses among more educated, older and wealthier mothers. Survey evidence reported in Quintena-Domeque et al. [2017] also finds that more educated mothers are more likely to report being aware of the association between Zika and microcephaly.
microcephaly risks across groups suggests that post-alert, all women take precautionary behaviors to avoid Zika, so that all indeed respond to information provided. The fact that all women—irrespective of their race, marital status, education, age, and socioeconomic status—are able to reduce the risks of microcephaly during pregnancy is not surprising, as most preventative measures are not costly (such as wearing long and light colored clothing, using mosquito repellent or insecticides etc.) However, it does suggest that the core point made in Figure 5—that there is selection of mothers into pregnancy post-alert—is driven by differential costs of delaying fertility across subgroups of women, rather than differences in the availability of, or response to, information per se across subgroups.

4.4 Behavior During Pregnancy

We next examine changes in behavior during pregnancy caused by the public health alert, as individuals are made aware they are at risk. We use the linked inpatient-outpatient administrative records to construct a city-month panel and estimate specifications analogous to (1) where the outcomes analyzed are pregnancy tests, ultrasounds, abortions and the total number of prenatal visits during pregnancies (where the last outcome is measured from birth records for pregnancies going to term). For all outcomes except prenatal visits, rates are calculated as the number of such outcomes in city \( c \) in time period \( t \) per 1000 women that conceived in the same city \( c \) in the previous three months, as only women in the first trimester of pregnancy are ‘at risk’ of each outcome. For prenatal visits, we calculate the average number of visits per pregnancy in the city-period, as measured at the end of the pregnancy.\(^{22}\)

Panel B of Table 1 presents descriptive evidence on these outcomes, by time period. We see little difference-in-difference in pregnancy test rates: these appear to be naturally rising over time. This sustained demand for pregnancy tests implies households were not avoiding hospitals during the epidemic for fear of contagion. As Table A1 showed, such avoidance behaviors occur less for Zika because the dominant transmission channel is via mosquitoes, not from others.

Pre-alert around a quarter of women undergo an ultrasound, and this rises significantly post-alert: the DD is 22 (\( p = .000 \)), corresponding to a 9% rise over the November-April period in pre-epidemic years. Despite severe legal restrictions, abortion rates are high pre-epidemic: around

\(^{22}\) These administrative records cover all abortions and ultrasounds in public and private hospitals. This is a lower bound on the true numbers because we omit illegal abortions and those taking place outside hospitals. Diniz et al. [2017] try to quantify the number of illegal abortions using the Brazilian National Abortion Survey of 2016. They estimate there were 416,000 illegal abortions in 2015. In half of these cases, women took some form of medication to conduct their abortion. The other half were hospitalized, so those abortions are recorded in our data. Our records show 1,445,425 abortions in hospitals in 2015. Combining this with the Diniz et al. [2017] estimate, we infer the share of abortions that are illegal is 213,000/1,445,425 = .147.
16% of women pregnant in the previous three months have an abortion (partly reflecting the lack of contraceptive access in this context), and this rises further post-alert: the DD is 8 (p = .004) corresponding to a 5% rise over the November-April period in pre-epidemic years. Finally, for pregnancies going to term, the number of prenatal visits does not differ across periods. Hence, there is no change in total exposure to health services using this measure.

Table 3 presents the regression results for these outcomes during pregnancy, making two further refinements. First, for each outcome (except prenatal visits), we examine two samples: all cities (as in Panel B of Table 1), and the subset of cities reporting a strictly positive outcome in at least one time period. This second sample is relevant because not all cities provide pregnancy tests, ultrasound or abortions in hospital, although the set of hospitals providing such services does not change over the course of the epidemic. Second, we split pre- and post-alert periods into quarters. This allows us to more precisely pin down changes in behavior among women that conceived in the pre- and post-alert periods. Recall, unlike the birth records used earlier, the inpatient-outpatient records contain no details on conception date, so outcomes are measured in the time period \( t \) when the event takes place. However, assuming pregnancy tests, ultrasounds and abortions occur in the first trimester of pregnancy, then by splitting pre- and post-periods into quarters, we are almost sure that those whose outcome occurs in the second quarter of the pre-alert period (from August to October 2015) conceived pre-alert, and similarly those whose outcome occurs in the second quarter of the post-alert period (from February to April 2016) almost certainly conceived post-alert. Hence the difference-in-difference that best isolates the pure impact of the alert on those that conceived pre- and post-alert compares between these quarters and pre-epidemic years. This DD is shown at the foot of each Column in Table 3.

The DD in pregnancy tests is not statistically different from zero. In contrast, the DD in ultrasound rates is positive and significant, in the all city sample as well as in cities where ultrasounds are available. The magnitudes of the effects are 39 and 45 respectively, that both correspond to 16% increases over the baseline rate.

The DD in abortion rates is positive and significant in both city samples. The magnitudes of the effects are 16 and 19 respectively, that both correspond to 9% increases over the baseline. These occur despite restricted access to abortions in normal times, and controversy over the use abortion during the epidemic. The response corresponds to just under 4,000 more abortions per

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23 There are legal restrictions on abortion in Brazil. Such procedures are only formally undertaken if there is a threat to the mother’s life, anencephaly (absence of a major portion of the brain, skull, and scalp that occurs during embryonic development), and in cases of rape (as long as two witnesses are produced). The administrative records suggest in practice, abortions occur far more frequently than in only those circumstances.

24 Religion plays an important role, with the church taking a conservative position. For example, as reported by O Globo on 5th February 2016, "...the National Conference of Brazilian Bishops (CNBB) declared that the occurrence
month post-alert, so adding a further 20% decline in cohort sizes over and above the 18,000 fall in monthly conceptions leading to a live birth documented earlier.

An alternative measure of abortions by city-month can be constructed using administrative records from the Mortality Information System (SIM). This covers all cities, but these records relate to fetal abortions with gestation length of at least 20 weeks, a weight of at least 500 grams and a physical length of at least 25 centimeters. Hence the SIM data measures late-term abortions. Column 4 of Table 3 shows that for late-term abortions, the key difference-in-difference is significantly greater than zero ($p = .000$), corresponding to a 15% increase in these late term abortions. Overall, our findings suggest that there are both more abortions post-alert, and a shift in the timing of abortions later in pregnancies. Some of these might well be among women that conceived just pre-alert and so could only possibly abort late in their pregnancy.

For ultrasounds and both measures of abortion, the DD is significantly different from zero and is driven by changes in behavior during pregnancy of those select group of mothers that conceived post-alert ($\beta_2 > 0$) rather than changes in behavior among (non-selected) mothers that conceived pre-alert ($\beta_1 = 0$). This lack of behavioral response during the first trimester of pregnancy is despite the unborn children of those that conceived pre-alert also obviously being at risk from ZIKV infection. This lack of response shows that not all at-risk households respond to public health alerts; this non-response is more in line with the kind of limited attention or endogenous belief formation that seems to explain many health behaviors outside of epidemics [Kremer and Glennerster 2012, Dorsey et al. 2013, Oster 2018]. Moreover, among mothers that conceive post alert, the significant increase in abortions suggests a second stage of selection into birth outcomes (beyond the first stage of selection into pregnancy as discussed above).

Finally, Column 5 shows the impact of the public health alert on the number of voluntary prenatal visits made during the entire pregnancy, among those going to term. Unlike the earlier outcomes, the outcome is measured in birth records, so we can measure it by month of (estimated) conception. Mothers that conceive during the Zika epidemic, either pre- and post-alert, have significantly more pre-natal visits over their pregnancy than women in pre-epidemic years. Hence there is greater exposure to the health service for mothers who conceived after Zika was known to be present in Brazil. While the DD shows there is a fall in the average number of prenatal visits for those mothers that conceive post-alert, the magnitude of this is small (corresponding to a 1% reduction in prenatal visits).

$^{25}$This is driven by a fall in the share of mothers with 7 or more pre-natal visits, and a significant rise in the share of with 1-3 or 4-6 visits (with no change in the share with zero visits).
4.5 Birth Outcomes

Birth outcomes are derived from birth records, and so can be defined for pregnancies conceived in period $t$, with outcomes measured as the rate per 1000 births in the city-month. Table 4 presents the results where we estimate a specification analogous to (1). To begin with, Column 1 shows the impact on miscarriages. The biological effect of Zika, $\hat{\beta}_1$, does not differ from zero, at least in aggregate across all miscarriage types. However for those mothers that conceive post alert, miscarriage rates significantly rise, with the DD being 4%.\(^{26}\)

We next document that children conceived post-alert are no more likely to be delivered by Cesarean section (Column 2), but are significantly more likely to be born premature, although the percentage impact is small (1.6%) (Column 3).

Birth weight is a widely used indicator of neonatal health and has been consistently shown to correlate with later life outcomes such as health, cognition, educational attainment, wages and longevity [Almond and Currie 2011]. In Column 4 we find that among those conceived pre-alert, the biological effect of the likelihood of low birth weight significantly increases relative to pre-epidemic years ($\hat{\beta}_1 = 1.75$, or 2% of the baseline mean). Among children conceived post-alert (i.e. among mothers that did not delay pregnancy) and that reached full term (i.e. among mothers that did not abort), the behavioral effect of the likelihood of low birth weight also rises relative to pre-epidemic years but by not as much ($\hat{\beta}_2 = .813$, or 1% of the baseline mean). Hence the DD overall falls between these two cohorts relative to pre-epidemic years.

We use two approaches to further investigate how these outcomes relate to post-alert selection into pregnancy and birth. First, we split outcomes between cities that do/do not offer abortion or ultrasound services in hospitals. Recall that neither service is universal: 31% of cities provide both, 45% provide neither, 15% provide only abortions, and 9% offer only ultrasound. The set of cities with the technology and infrastructure to offer these services does not change over the epidemic. Table A3 shows that: (i) the DD in premature births is driven by cities that offer ultrasound or abortion (Panel A); (ii) the DD in low birth weights is also driven entirely by cities that offer ultrasound or abortion (Panel B).\(^{27}\)

Our second approach addresses the post-alert selection of mothers into pregnancy more directly, following an approach similar to Currie and Schwandt [2014]. To begin with, in Table A4 we show how the demographic characteristics of mothers are impacted over the outbreak, by estimating specification (1) but where the outcome is the percentage of pregnancies to teen mothers in the city-month, the percentage of non-white mothers, the percentage of pregnancies with missing data

\(^{26}\)We find no change in sex ratios at birth over the course of the epidemic.

\(^{27}\)We find that there is no impact on child gender or the incidence of twin births either in the pre- or post-alert periods, so there appears to be no selective abortion on those grounds.
on fathers’ age (as a proxy for out-of-wedlock pregnancies), the percentage of mothers with basic education, and the average age of mothers. The results show a precise DD in the composition of mother characteristics, with a greater share of teen mothers, pregnancies missing fathers’ age, mothers with basic education and an overall reduction in average age in the post-alert period in the epidemic year relative to pre-alert periods in earlier years. However, the magnitude of these changes is relatively small (ranging from .6% to 3% of the baseline mean). Reassuringly, we find no biological impact of Zika on the composition of mothers: \( \hat{\beta}_1 \) is precisely estimated to be zero for each characteristic.

To examine how such compositional changes relate to birth outcomes, Table 5 presents results directly controlling for these characteristics of mothers, and interactions of each with \( (POST - ALERT_m \times Zika_t) \). Comparing Tables 4 and 5 we see the DD in outcomes becomes less pronounced once we account for changes in mother characteristics post-alert. Once selection is accounted for, there only remains a significant fall in the likelihood of being born premature post-alert \( (\tilde{\beta}_2 < 0) \). This is consistent with those children that were aborted post-alert being those most at risk of being born prematurely in the counterfactual absent the Zika epidemic.\(^{28}\)

### 4.5.1 Microcephaly and Other Congenital Malformations

The final set of birth outcomes we examine are Zika-specific risks: the incidence of microcephaly and other congenital malformations. Panel C of Table 1 presents descriptive evidence on these outcomes across time periods, defined by month of conception. The pre-alert incidence of microcephaly is low: .06 per 1000 births (or 1 in 17,000 births) of those conceived May to October are diagnosed with microcephaly, with no seasonal trend in its incidence; (ii) post-alert, the incidence of microcephaly among those conceived pre-alert rises by factor of 13, while for those conceived post-alert it falls by 36%. The DD is \(-1.00\) \((p = .019)\).

For other congenital malformations, there are also no seasonal trends, and there is no change in incidence between those conceived pre- and post-alert.

Columns 5 and 6 in Table 4 show the regression adjusted estimates (not controlling for mother characteristics). Column 5 shows a marked rise in microcephaly in children conceived pre-alert: the biological effect \( \hat{\beta}_1 \) shows the incidence of microcephaly rises by .808 per 1000 births, relative to a baseline mean of .061. This represents a 1324% increase in microcephaly cases due purely to the biological effects of ZIKV. For those select children conceived post-alert, there is no significant difference in rates of microcephaly relative to children born in similar months in pre-epidemic

\(^{28}\)We cannot examine miscarriages conditional on mother characteristics because the inpatient-outpatient records used for that outcome do not contain information on patient demographics.
years: $\hat{\beta}_2 = -0.239$ and is not statistically different from zero. The DD is $-1.04$, corresponding to a 1700% reduction in microcephaly rates among those conceived post-alert relative to those conceived pre-alert. Hence despite post-alert births being concentrated among younger and lower SES mothers, these findings are again entirely consistent with these mothers taking offsetting precautions to mitigate the risk of Zika infection during pregnancy (as Figure 6 suggested). This represents a third dimension of prevalence-response to the epidemic (beyond delayed conception and aborting pregnancies). Moreover, once we control for the composition of mothers, we see a similar pattern of results emerge in Column 4 of Table 5: the biological effect $\hat{\beta}_1$ shows that the incidence of microcephaly rises by .790 per 1000 births, that is near identical to the estimate in Table 4. The behavioral effect $\hat{\beta}_2$ remains not different from zero.\(^{29}\)

This conclusion does not change if we split the sample between cities that do/do not offer abortion or ultrasound services. As Panel C in Table A3 shows, the DD impacts on microcephaly are similar across all cities: as expected, this suggests ultrasound technology is unlikely to detect microcephaly during the first trimester of pregnancy, when abortion remains possible.

On other congenital malformations, the final Column of Table 4 shows similar increases pre-and post-alert. However, medical understanding of other congenital malformations related to Zika has evolved since the epidemic. For example, it is now better established that ZIKV infection can result in a congenital malformations including those relating to brain, eye and hearing anomalies [Rice et al. 2018]. Using ICD-10 codes, we thus estimate impacts by diagnosis.

Figure 7 summarizes the estimates of $\hat{\beta}_1$, $\hat{\beta}_2$ and $\hat{\beta}_2 - \hat{\beta}_1$. Panels A and B are on very different y-axis scales. Panel A focuses on congenital malformations, such as microcephaly, where the estimated coefficients are large in absolute value. We see that microcephaly is the most impacted outcome for children conceived pre-alert. We also note increases in ankyloglossia (ICD Q381, tongue-tie) among those conceived over the epidemic but these are not precisely estimated. On the rarer conditions shown in Panel B, those conceived pre-alert are significantly more likely to be born with dextrocardia (ICD Q240, a rare condition in with the heart is on the wrong side of the chest), and those conceived post-alert are significantly more likely to be born with dolichocephalics (ICD Q67.2, an unusually long skull). These administrative records are the best possible data source for understanding potential impacts of the Zika epidemic on a wider range of congenital malformations: with the obvious small sample caveats, they confirm some of the ongoing discussion in the medical literature on the wider impacts of ZIKV on newborns beyond

\(^{29}\)Note that the WHO communique in December 2015 stated there had been a 20-fold increase in microcephaly in Brazil, while the administrative records show a 13-fold increase. The difference is due to regression adjustments, and also because there was likely an over-reporting of microcephaly cases during the outbreak, while the incidence reported in birth record data all comes from physician diagnosis.
microcephaly, that was the primary concern during the epidemic.

The final Column of Table 5 shows how the results change conditional on the composition of mothers: as expected the biological impact $\tilde{\beta}_1$ is unchanged, while the behavioral effect $\tilde{\beta}_2$ changes sign and is no longer different from zero: in line with the incidence of microcephaly, this again suggests mothers that conceived post-alert took precautions to mitigate risks during pregnancy that left the incidence of other congenital malformations unchanged from pre-epidemic years.

### 4.5.2 Dynamics of Microcephaly

To get a clear sense of the time series incidence of microcephaly over the epidemic, we estimate a specification analogous to (2), where the outcome is whether a newborn, that was conceived in time period $t$ is born with microcephaly. Figure 8A shows the complete set of dynamic DD estimates, stretching back to more than one year pre-alert, and running through to newborns conceived up to 7 months post-alert. Reiterating the regression results, this clearly shows that those conceived pre-alert are at significantly higher risk of microcephaly. The peak risk occurs for those conceived 8 months pre-alert, in March 2015, but microcephaly cases start rising from December 2014. Recall that it was in March 2015 that the WHO received notification from the Brazilian government regarding an illness transmitted by the *Aedes Aegypti* mosquito, but not detected by standard tests (in April 2015 the first case of ZIKV was confirmed). It was as late as October before the Secretary of Health from Pernambuco alerted the Federal government about the risk in microcephaly cases in that state in the North East. The DD estimates on microcephaly from administrative birth records thus suggest the virus might have been present in Brazil months before officially noted, and that among those conceiving pre-alert, those conceived very early in the epidemic were most at risk of microcephaly because at that point in time less was known about the causes of microcephaly and hence the preventive actions that individuals could take.  

Figure 8B repeats the analysis by region: it shows the pre-alert impacts are nearly all driven by increases in microcephaly cases in the North East, with there also being significant increases in microcephaly in the South East (although the magnitude of the response is far smaller).

As with our earlier analysis of administrative data from doctor-patient meeting notes (that highlighted a potential link between Zika and pregnancy), these results suggest that had it been possible to analyze administrative birth records in real time, authorities might have become aware

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30 We could use the incidence of microcephaly to back out estimates of the incidence of Zika in the population, but this requires many assumptions: (i) the risk of microcephaly if ZIKV infection occurs in first trimester of pregnancy; (ii) if ZIKV infection occurs in the last two trimesters it does not result in microcephaly; (iii) ZIKV infection is equally likely in any trimester of pregnancy; (iv) pregnant women are as likely to be infected with Zika as non-pregnant individuals.
of the spike in microcephaly months before it was actually realized.\textsuperscript{31}

\section*{4.6 Supply Side Responses to the Epidemic}

In the Appendix we present evidence using administrative records on supply side responses to the epidemic. This allows us to document how health care personnel changed behavior after the public health alert, and the threat from Zika became better understood.

We find no impact in the frequency of counseling on contraceptives offered by health personnel, despite the fact the alert recommending health authorities strengthen pre-pregnancy counseling to women wanting to conceive. Nor do we find evidence on changes in the organization of hospitals.

Like many new viral outbreaks, testing for the virus during the early stages of the epidemic is difficult if not impossible. We study the issue in the Zika epidemic by estimating how health personnel used tests for dengue (that absent a test for Zika was the best available alternative for diagnosis). As shown in the Appendix, health care personnel increasingly administered dengue tests on pregnant women post-alert, but this just led to large rises in negative dengue test results (878\%), and inconclusive test results (1600\%).

\section*{5 External Validity}

Nearly all viral outbreaks increase the risks and uncertainty households face, as they emerge without warning and without treatment being available. As such, public health alerts are a vital tool policy makers have in the early stages of epidemics, when behavioral responses of households play a key role in determining the severity of viral outbreaks. There are different ways to consider the external validity of our findings to alternative contexts or other viral outbreaks.

In terms of future viral outbreaks where those at most risk are again pregnant mothers, we have to consider whether Brazil differs from other countries in terms of the availability of, and attitudes towards, contraceptives and abortion. World Bank data records that 80\% of women aged 15-49 in Brazil report using some form of contraception. Brazil thus ranks only behind Argentina in Latin America in terms of contraceptive prevalence (the average on the continent is 75\%, and globally it is 63\%). This data also confirms that nearly all women in Brazil (97\%) report receiving prenatal care. Access to abortion is however more restricted in Brazil compared to neighboring countries, and this is mirrored in attitudes towards abortion. Data from the 2014 World Values Survey (WVS) on attitudes towards abortion shows that 66\% of Brazilian men

\textsuperscript{31}This earlier timing still matches with the claimed origins of ZIKV in Brazil: the Va’a World Sprint Championship canoe race, held in Rio in August 2014, that had participating athletes from French Polynesia, New Caledonia, the Cook Islands and Easter Island – all countries with a high incidence of Zika at the time [Triunfol 2016].
and 74% of Brazilian women respond that abortion is never justified. This is higher than in other countries in the region, where 53% of men and women report abortion never being justified. Despite these attitudes, our analysis showed a significant rise in abortion rates by around 9% among those that conceived post-alert, and no supply side responses related to the provision of contraceptives. We thus might expect both behavioral responses to be larger in less conservative contexts.\footnote{In line with this prediction, we note that Gamboa and Lesmes [2019] estimate that Zika in Colombia led to a 10% reduction in birth rates, so slightly larger than the magnitude we find in Brazil.}

The second dimension of external validity relates to insights for future viral epidemics. Of course, all viral outbreaks differ from each other in the extent to which: (i) some individuals are more at risk than others; (ii) their primary vector of transmission; (iii) their degree of contagion, or basic reproduction number (R0); (iv) case fatality rates.

At the same time, by their very nature, nearly all novel viral epidemics occur without there being known treatment or vaccine. Hence, during all such epidemics, individuals are exposed to increased risk, and increased uncertainty as the length and severity of outbreaks is unknown [Rasul 2020]. As in any pandemic such as Zika and COVID-19, countries have the opportunity to quickly learn from their neighbors and international scientific cooperation is key.

Our analysis shows that a large share of women at risk during the Zika epidemic in Brazil responded to new information, despite the risk of microcephaly being relatively low. We might expect even larger behavioral responses to health alerts for viruses with higher case fatality rates. Our findings strongly suggest responses to health alerts during epidemics will be heterogeneous across groups, and that two margins of heterogeneity might be especially important for policymakers to consider: (i) those for whom behavioral change is most costly, such as the cost of delaying fertility for low SES women in our study context; (ii) those that entered the risky state pre-alert, who for a variety of reasons might be unwilling to respond to new information despite the fact that they are at risk. It is among this latter group that alternative interventions could be targeted, perhaps leveraging a work using behavioral insights to shift behavior [Haushofer and Metcalf 2020].

6 Conclusions

As we write, the world is gripped by the COVID-19 pandemic, that threatens to overrun the health infrastructures of many countries, and through heightened risks and uncertainty, drive many into recession. The fact that the fabric of many rich societies has proven to be so vulnerable to such aggregate shocks should not be a surprise. There has been rising recognition that the frequency
and diversity of viral outbreaks is increasing over time [Smith et al. 2014]. Given underlying forces driving this, all countries need to prepare to combat such shocks, yet most have low investment in disease surveillance and diagnostic laboratories, that aid early identification, response, and containment of epidemics [World Bank 2017]. As the current pandemic demonstrates, this level of investment is likely suboptimal given: (i) the huge expected economic losses; (ii) complementarities between epidemic preparedness and the regular functioning of health services; (iii) the limited ability of international agencies to immediately respond to outbreaks [Currie et al. 2016]. This final point has been shown at various points of our analysis: had administrative data been available and analyzed in real time – in relation to doctor’s notes, or microcephaly among newborns – the link between Zika and pregnancy might have been noted some months prior to official public health alerts being made.

With a lack of preparedness, especially in countries with low state capacity, it is vital to understand the endogenous responses of households and health care personnel to new public health information at the time of new and rapidly spreading epidemics. Such prevalence elasticities and disease avoidance behaviors are often the first order welfare cost of epidemics, form the key wedge between economic and epidemiological models of disease diffusion, and have implications for policy design and targeting. Such an analysis lies at the heart of this paper.

Our analysis provides two major implications for the wider literature. First, there are significant changes in cohort size given disease avoidance responses, as well as biological impacts of ZIKV on birth weights, and congenital malformation. The quantity-quality impacts in the affected cohort will ripple through health and education systems over time as the cohort ages (with potential spillover effects on adjacent birth cohorts). The medical literature suggests that as infants with congenital Zika infection get older, problems such as epilepsy, vision loss, and developmental delays are increasingly recognized [Rice et al. 2018]. Hence, as Currie et al. [2016] emphasize, death and disease stemming from epidemics are likely to linger even after a country is declared disease-free. In the poorest countries, strained health systems can be further weakened, persistently worsening responses to future infectious disease outbreaks. Of course, counter to such persistence, other evidence from epidemics suggests there might be long run gains to health behaviors if exogenous health shocks facilitate the permanent adoption of health-improving behaviors [Aguero and Beleche 2017]. Much remains to be understood on all these longer term implications of epidemics – indeed, there seems to be little doubt that the current pandemic will have long lasting impacts on social and economic life.

Second, on research methods, we have used administrative data to study behavioral responses during the epidemic. Beyond its scale and detail that allows for well powered tests for hetero-
geneous responses, the other central advantages over household survey data are that diagnosis reports based on trained professionals reduce recall bias and other measurement errors, and also mitigates concerns over experimenter demand effects [Kremer and Glennerster 2012]. Of course there is rich scope to combine such data with opportunistically timed randomized control trials. Such coincidences are already shedding light on the kinds of ex ante interventions that can foster trust in health care providers and thus reduce avoidance behavior during epidemics [Christensen et al. 2019], or to shed light on the economic, health and social channels through which aggregate health shocks impact individuals [Bandiera et al. 2018].

As the frequency and diversity of viral outbreaks increases, then as Currie et al. [2016] argue, perhaps the most successful approach to studying and curtailing future outbreaks will be to coordinate knowledge across disciplines and data scientists. There is a need to simultaneously draw on medical knowledge of transmission mechanisms and impacts of viruses, to include these features in epidemiological models of diffusion, and then embed economic analysis into these models to account for endogenous responses of households and health personnel to epidemics and policy.

The current global crisis leaves little doubt that we cannot ignore this challenge any longer.

A Data Appendix

We primarily use four sets of administrative records for our analysis: (i) the live birth information system (SINASC); (ii) the Hospital Information System (SIH); (iii) the Ambulatory Information System (SIA); (iv) the national system of notifiable diseases (SINAN). These are web-based systems providing near universal coverage of birth and health care statistics from all 27 states (the 26 states and one federal district) and 5565 municipalities (cities) in Brazil.

SINASC (Sistema de Informações sobre Nascidos Vivos) This covers all live births in the Brazilian territory. The data is collected at hospitals, birth civil registries and city councils, and is updated every 18 months. It details characteristics of mothers giving birth and birth outcomes (including congenital malformations). The dataset is constructed in three stages: (i) the Federal government sends questionnaire to local authorities; (ii) hospitals and civil registries collect birth information on all births; (iii) the data is reviewed and sent back to Federal authorities. In the first step, the Federal government sends standardized questionnaires on the Declaration of Live Births (DN, in Portuguese) to health secretaries of each State. The number of questionnaires distributed is the total number of births during the previous year, plus and additional 20%. State health secretaries are responsible for then distributing questionnaires to municipalities. At the second stage, with the DNs in hand, hospitals and civil registries (for births outside hospitals)
collect information on births and pregnancies. Hence, the questionnaires are filled by doctors and other trained professionals. After all information is sent back to municipal health secretaries, a municipality level SINASC is then constructed. This information is reviewed in terms of incomplete or missing variables. After review, the information is forwarded to State health secretaries, from municipality to state governments, and from states to the Federal government.

*SINASC* identifies mother’s city of residence, the hospital in which the birth occurs (or other location if the birth is outside hospital), the exact date and hour of birth, and the date of last menstruation. It is this information on last menstruation and a doctor’s assessment that allows for the pregnancy date to be estimated. The characteristics of mothers recorded include their age in years, race, education (in categories), marital status, the number of previous children, abortions and C-sections. The birth outcome covariates include the child’s gender, if it is a twin birth, birth weight (in grams), APGAR 1- and 5-minute scores, Robson scores, and whether the birth was a C-section. The estimated pregnancy date is then used to estimate pregnancy length (in weeks). Father’s age is also recorded, but is often missing. Finally, the data records whether there was any congenital malformation: international disease codes (ICD-10) are provided for congenital malformations, where microcephaly is listed under ICD Q02.

Our data covers 14,016,866 births from January 2013 to December 2017. We do not use data from January 2018 onwards because those registration records are as yet incomplete. Focusing on women aged 12 to 49, we drop those records that have missing data on last menstruation date (as they are required to construct the estimated conception date). The leads to 2.63% of records to be dropped. We have data for births in 2012, but we only use these for one robustness check because 4.81% of 2012 records have missing data on last menstruation date, so it appears as if the recording of this information has improved over time.

**Hospital Information System (SIH)** This provides inpatient data for all public hospitals and a subset of private hospitals that work with the National Health Service (SUS), and are paid to care for patients: this covers more than 70% of hospitalizations. These administrative records are updated every two months. The data is collected at the point of hospital admission for each patient. It records their city of residence and the exact date of admission. However, it does not provide any patient characteristics. Primary and secondary reasons for admission are coded using International Disease Codes (ICD-10). Unique codes are provided for each medical procedure undertaken, with separate codes for primary and secondary medical procedures. Reason for hospital discharge are also provided.
Ambulatory Information System (SIA)  This provides outpatient data for all public hospitals and a subset of private hospitals that work with the National Health Service (SUS). These administrative records are updated every two months. In contrast to the inpatient records, the SIA do record patient characteristics including their age, gender, race, migrant status, city of residence and reason for leaving the hospital. They record the exact date of appointment, and when the appointment was recorded in the system. Primary and secondary reasons for admission are coded using International Disease Codes (ICD-10). Unique codes are provided for each medical procedure undertaken, with separate codes for primary and secondary medical procedures. The complexity of procedures is also recorded.

The SIH-SIA data we have access to covers inpatient and outpatient records from January 2013 until June 2017. This covers over 400 million patient appointments. The relevant outcomes that are only available in the outpatients data include the use of tests for pregnancy, dengue, Zika, Zika diagnosis, and the use of neonatal triage. Hence the need to merge the inpatients and outpatients data. We thus merge the SIH and SIA records by city-month, covering all public hospitals in Brazil. In SIA the unique city-identifier is PA_MUNPCN and in SIH the unique city-identifier is MUNIC_RES. The inpatient data records the exact data of admission, while the outpatient data record the month of release.

The definitions/codes used for key variables are as follows. For abortions, we combine ten abortion procedures reported in ICD codes O00-O09. For ultrasounds, we combine information from doppler obstetric ultrasound (code 0205010059), obstetric ultrasound (code 0205020143) and obstetric ultrasound with colored doppler (code 0205020151). For prenatal visits, we combine information from prenatal visit (code 0301010110), prenatal visits for the partner (code 0301010234), incentive PHPN of prenatal (code 0801010012) and concluding prenatal assistance (code 0801010020). For dengue, we use diagnoses of classic dengue (ICD code A90) and hemorrhagic fever due to dengue (ICD code A91). For pregnancy tests we use fast pregnancy tests (code 0214010066). For neonatal triage we use collection of blood for neonatal triage (code 0201020050).

Sistema Nacional de Agravos Notificáveis (SINAN) This is the national system of notifiable diseases, that covers all cases of dengue in the Brazilian territory. This is updated at least four times per year. The data is collected at hospitals, at the time of inpatient appointments, with the exact notification date. It only records cases of dengue. The records contain patient characteristics such as date of birth, age, gender, race, education category, marital status, if twin, number of children, city of residence, if pregnant and trimester of pregnancy. Dengue cases are recorded using ICD-10 codes (ICD-10) for dengue (ICD A90 and A91). Our sample covers the
period January 2013 until December 2017, with over 3 million patient samples. The data from 2016 does not provide doctors’ notes, and so is not useful for our analysis.

**Other Data**  
*DATASUS* 2012 provides information about the number of women living in each municipality in 2012. We use this as the denominator for our conception rate estimates. To generate population counts by city in 2012, the Ministry of Health and the Brazilian Institute of Geography and Economy use information on the gender and age categories from the 2010 Census to project population numbers for 2012. These projections are for population on 1st July.

The Cadastro Nacional de Estabelecimentos de Saúde (*CNES*) is the National Register of Health Establishments that provides data on all public and private hospitals. Hospitals provide monthly reports to the Federal government, and the database is then updated every three months. It records the number of rooms and beds available, by speciality, at each hospital. It also records other hospital facilities, and the existence of various hospital committees.

On newspaper archives, we searched online archives of the three leading national newspapers in Brazil: *Folha de Sao Paulo*, *Estadao* and *O Globo*. These searches cover both online and national editions of each newspaper, and we exclude regional printed editions. The data from *Folha de Sao Paulo* was obtained via https://acervo.folha.com.br/index.do. The data from *Estadao* was obtained via https://acervo.estadao.com.br/. The archive from *O Globo* was obtained via https://acervo.oglobo.globo.com/. In each archive, we searched for “microcefalia” (microcephaly, in Portuguese). The search engines are not case sensitive and go back at least 20 years. The searches provide the exact date when the word searched for was published along with the number of times it appears per page. If the word microcephaly appears twice in the same page, it is counted twice.


**B Supply Side Responses to the Epidemic**

To enrich our understanding of what might partly be driving household behaviors over time, we also study supply side responses to the epidemic as measured by changes in behavior among health care personnel, be they physicians, nurses or other workers women come into contact with during pregnancy. We use two administrative data sources to document these changes: (i) the national system of notifiable diseases (*SINAN*), that covers all cases of dengue in Brazil; (ii) inpatient-
outpatient records that detail procedures implemented on patients (as recorded by physicians). The results are in Table A5 where all outcomes are measured in period $t$ for each city-month.

**B.1 Administering Dengue Tests**

Recall that pre-alert, the belief among the public and health personnel was that Zika had dengue-like symptoms, with no consequence for those *in utero*. Our first outcome is thus taken from SINAN and examines the rate of dengue tests administered to pregnant women (in those cities where dengue tests are conducted), measured per 1000 women that conceived in the same city in the previous 8 months (so corresponding to the stock of pregnant women in city $c$ in period $t$).

The result in Column 1 shows: (i) no change in the use of dengue tests among pregnant women during the pre-alert period ($\beta_1 = 0$) (ii) a rise in the use of dengue tests for pregnant women post-alert ($\beta_2 > 0$): the DD corresponds to a 249% increase over the baseline mean. To gauge the speed of response, Figure A2A shows the rate of dengue tests administered to pregnant women, by week, in a narrow window around the health alert. Although the series is noisy, there is a clear structural break in the use of dengue tests for pregnant women in the week after the alert, with a rising trend thereafter. Furthermore, on dynamic behavioral changes, Figure A2B plots the dynamic DD estimates from a specification analogous to (2) for dengue test rates for pregnant women. We see that pre-alert, there was no change in the administration of these tests relative to earlier pre-epidemic years, and that post-alert there was a steady increase in their usage. This peaked some three months after the alert, and declined back to trend eight months post-alert (so around the time that conception rates had also returned to pre-epidemic trends).

Absent a widely available test for ZIKV, there is a rationale for administering dengue tests: as Zika is still closely related to dengue, serologic samples may cross react in tests for either virus [Petersen *et al.* 2016]. However, on the outcomes of these dengue tests, Columns 2 and 3 in Table A5 show that post-alert, there are even larger percentage increases in negative dengue test results for pregnant women (878%), and inconclusive test results (1600%). The increase in negative/inconclusive results capture a combination of women taking precautionary actions to avoid mosquito bites because of the health alert that could then reduce the incidence of dengue, women with Zika infections remaining undiagnosed post-alert, as well as the more widespread administration of dengue tests to women who did not actually have Zika nor dengue.\(^\text{33}\)

If this inability to diagnose Zika weakened trust in health care providers, it did not substantively reduce the number of individuals/pregnant women seeking health care, as evidenced earlier.\(^\text{33}\)

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\(^{33}\)Table A6 shows how the post-alert impacts on dengue tests vary by region (where the South is the omitted region). We see that: (i) the administration of tests increases most in the Centre West and North; (ii) there are large increases in negative or inconclusive test results in the North East, the region most impacted by Zika.
B.2 Zika Diagnosis

At the onset of the epidemic, doctors lacked knowledge on how to diagnose Zika, and there was no formal way of recording such diagnoses in any case. To overcome the second issue we use ICD-10 code A92.8 for primary diagnoses, that refers to ‘Other specified mosquito-borne viral fevers’, and what Brazilian health authorities recommended using to report suspected Zika cases. The linked inpatient-outpatient administrative records do not identify patient characteristics, so we measure the rate of Zika diagnosis per 100,000 of the population as a whole.

Column 4 in Table A5 shows a large increase in diagnosed cases of Zika infection over the epidemic (both pre and post-alert), but the increase is 10 times larger post alert. The DD corresponds to a 1466% increase in Zika infection rates. Beyond these diagnosed cases, there might also be undiagnosed cases of Zika. We define these as cases where a doctor has performed tests for dengue, yellow fever and chikungunya (all transmitted by *Aedes Aegypti*), but did not diagnose any of these. Here we see rises in potentially undiagnosed cases of Zika over the course of the epidemic, with the DD corresponding to a 22% increase. Reassuringly, the magnitudes of undiagnosed Zika cases are always smaller than for diagnosed cases.

To chart the dynamics of Zika diagnosis, we estimate a specification analogous to (2). Figure A3 shows the DD estimates. Pre-alert, there are almost no changes in the incidence of Zika diagnosis relative to pre-epidemic years. There is a clear rise in Zika diagnosis post-alert: this peaks 4 months after the alert, and remains significantly higher up to 7 months post-alert. The gap in timing between the actual incidence of Zika and when it was being diagnosed by health personnel is then seen by comparing Figures 8 and A3. The peaks are 12 months apart, suggesting a year lag in the peak of ZIKV infection and Zika diagnoses by health personnel.

B.3 Counseling on Contraceptive Use

Column 6 of Table 6 investigates the other policy relevant dimension of personnel behavior: counseling those at risk of becoming pregnant on contraceptive use (per 1000 women). We see no post-alert impact on such counseling offered by health personnel in hospitals, despite the public health alert recommending health authorities strengthen pre-pregnancy counseling to women wanting to get pregnant. We can interpret the lack of response of health personnel as a supply side reaction, so that the advice actually given to women on avoiding pregnancy was not as strong as in other countries, nor was there an effort to improve the forms of contraception available to women. However, these results are also in line with qualitative evidence that the demand for
contraceptives did not change over the epidemic [Bahamondes et al. 2017, Borges et al. 2018].

The final outcome considered is diagnosis of eclampsia: this acts as a placebo to check for
greater attention being paid to pregnant women over the epidemic, as well as a weak proxy for
stress during pregnancy given it is caused by high blood pressure: reassuringly we find no change
in the rate of diagnosis of eclampsia pre- or post-alert relative to pre-epidemic years, and the
difference in difference is a precisely estimated zero (Column 7).

B.4 Hospital Functioning

We examine hospital functioning over the crisis using the National Register of Health Establish-
ments (CNES). This records the number of rooms and beds available, by obstetric and neonatal
speciality, at each hospital. It also records hospital facilities and the existence of hospital commit-
tees. In line with expectation, we find little supply side response in terms of the aggregate supply
or organization of hospitals over the crisis. Hence none of the documented behavioral responses
of households should be driven by changes in the supply of health services.

References


Health Behaviors: Evidence from the 2009 H1N1 Pandemic in Mexico,” Journal of Health
Economics 54: 40-55.

34 The inpatient-outpatient administrative records also detail a number of others behaviors of health care personnel
at the point of delivery, such as assisting pregnant women or incentivizing births. These are not clearly defined,
and leave more scope for subjective reporting by personnel. Hence we do not give much prominence to these
outcomes. Finally, we note there is no change in induced births (in line with the earlier result of no change in
births by Caesarean section), and no change in the use of neonatal triage (the process of short-term evaluation and
management of infants after delivery). Triage infants can responsible for a significant fraction of total intensive
care resource utilization, although at baseline only 2.3% of newborns are triaged.

35 On the number of obstetric centers and the number of neonatal centers we find the difference-in-difference in
health service provision is not statistically different from zero. One dimension of health service provision that does
increase post-alert is the number of hospital beds available for pregnant women (measured as a rate is per 1000
conceptions in the city in the previous eight months): the supply of beds increases by 5% post-alert relative to the
pre-alert period. On the organization of hospitals, we find no changes in hospital functioning as measured by the
number of committees tasked to control infections or to issue notifications on diseases.


“Requests for Abortion in Latin America Related to Concern about Zika Virus Exposure,”


tions of Zika Virus and Congenital Zika Syndrome for the Number of Live Births in Brazil,”
PNAS 115: 6177-82.


in West Africa,” PLOS Computational Biology.


Lives of Young Women in the Time of Ebola: Lessons from an Empowerment Program, mimeo UCL.


### Table 1: Conceptions, Behavior During Pregnancy and Congenital Malformations

City-month observations, weighed by 2012 city population of women aged 12-49

Means, standard deviations in parentheses and test of equality in brackets

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Pregnancy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conception Rate</td>
<td>4.24 (.990)</td>
<td>3.91 (1.02)</td>
<td>4.19 (.979)</td>
<td>3.57 (.985)</td>
<td>-.296 (.035) [0.000]</td>
</tr>
<tr>
<td>B. Behavior During Pregnancy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pregnancy Test Rate</td>
<td>6.39 (20.1)</td>
<td>6.32 (18.0)</td>
<td>12.4 (30.1)</td>
<td>14.1 (32.8)</td>
<td>-.197 (.776) [.802]</td>
</tr>
<tr>
<td>Ultrasound Rate</td>
<td>248 (355)</td>
<td>247 (267)</td>
<td>250 (275)</td>
<td>275 (289)</td>
<td>22.4 (3.06) [.000]</td>
</tr>
<tr>
<td>Abortion Rate</td>
<td>163 (173)</td>
<td>164 (157)</td>
<td>166 (154)</td>
<td>174 (166)</td>
<td>7.80 (2.49) [.004]</td>
</tr>
<tr>
<td>Number of Prenatal Visits</td>
<td>7.68 (1.10)</td>
<td>7.75 (1.11)</td>
<td>7.81 (1.08)</td>
<td>7.91 (1.12)</td>
<td>-.016 (.025) [.523]</td>
</tr>
<tr>
<td>C. Congenital Malformation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microcephaly Rate</td>
<td>.061 (1.16)</td>
<td>.061 (1.50)</td>
<td>.830 (4.50)</td>
<td>.529 (3.57)</td>
<td>-1.00 (.404) [.019]</td>
</tr>
<tr>
<td>Other Congenital Malformation</td>
<td>7.43 (13.9)</td>
<td>7.56 (14.2)</td>
<td>8.23 (14.4)</td>
<td>8.77 (16.4)</td>
<td>.110 .168 [.516]</td>
</tr>
<tr>
<td># of City-month observations</td>
<td>56,776</td>
<td>32,726</td>
<td>27,550</td>
<td>26,401</td>
<td></td>
</tr>
<tr>
<td># of birth records</td>
<td>3,039,169</td>
<td>1,401,357</td>
<td>1,503,802</td>
<td>1,278,138</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:** This presents descriptive statistics for pregnancies that were conceived between May 2013 and April 2016, split into sample periods. Conception dates are recovered using information on the last menstruation date, and by subtracting the number of gestational weeks or categories of length of gestation from the exact date of birth. On the 11th November 2015 the Brazilian government officially announced the association between the upsurge of Zika and microcephaly in Northeastern Brazil. This analysis excludes mothers aged below 12 or older than 49. Observations are weighted by the number of women in the city in 2012. The standard error on the difference-in-difference is calculated from the corresponding OLS regression equation where we cluster standard errors by state. Outcomes in Panels A, C, D and E are derived from the SINASC birth records. Outcomes in Panel B are derived from SIH/SIA inpatient-outpatient records. In Panel A, conception rates are calculated considering the number of women starting their pregnancy per month per 1,000 women living in the same city. The population of women in the city is derived from DATASUS and is for 2012. In Panel B, the pregnancy test rate is the number of pregnancy tests per 1,000 women pregnant in the last 3 city-months. The ultrasound and abortion rates are per 1000 pregnant women in the last 3 city-months, derived from the SIH/SIA data. In Panel C, the outcomes are measured at the date of birth (and so do not correspond to month of conception).
Table 2: Conception Rates

Dependent variable: Conception Rate
City-month observations, weighed by 2012 city population of women aged 12-49
Standard errors clustered by state in parentheses

<table>
<thead>
<tr>
<th>Month of Conception</th>
<th>(1) City Fixed Effects</th>
<th>(2) Month Fixed Effects</th>
<th>(3) Month and City Fixed Effects</th>
<th>(4) Temperature Controls</th>
<th>(5) State Specific Trends</th>
<th>(6) State Specific Trends (Squared)</th>
<th>(7) City Specific Trends</th>
<th>(8) Regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zika: Pre-Alert ($\beta_1$)</td>
<td>-0.044*</td>
<td>-0.044*</td>
<td>-0.044*</td>
<td>-0.013</td>
<td>-0.087***</td>
<td>-0.087***</td>
<td>-0.087***</td>
<td>-0.005</td>
</tr>
<tr>
<td>(0.023)</td>
<td>(0.023)</td>
<td>(0.023)</td>
<td>(0.019)</td>
<td>(0.021)</td>
<td>(0.021)</td>
<td>(0.022)</td>
<td>(0.018)</td>
<td></td>
</tr>
<tr>
<td>Zika: Post-Alert ($\beta_2$)</td>
<td>-0.340***</td>
<td>-0.339***</td>
<td>-0.340***</td>
<td>-0.319***</td>
<td>-0.393***</td>
<td>-0.393***</td>
<td>-0.393***</td>
<td>-0.424***</td>
</tr>
<tr>
<td>(0.030)</td>
<td>(0.030)</td>
<td>(0.030)</td>
<td>(0.032)</td>
<td>(0.034)</td>
<td>(0.034)</td>
<td>(0.035)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zika: Pre-Alert x North East</td>
<td>-0.424***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.090)</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Zika: Post-Alert x North</td>
<td>-0.145***</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(0.050)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Zika: Post-Alert x South East</td>
<td>-0.311***</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>(0.029)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Zika: Post-Alert x Centre West</td>
<td>-0.352***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.056)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zika: Post-Alert x South</td>
<td>[omitted]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Difference-in-Difference

| Zika: Pre-Alert ($\beta_1$) | -0.296*** | -0.296*** | -0.296*** | -0.306*** | -0.305*** | -0.306*** | -0.305*** |
| (0.035) | (0.035) | (0.035) | (0.032) | (0.031) | (0.031) | (0.032) |
| Zika: Post-Alert ($\beta_2$) | [-0.368, -0.222] | [-0.367, -0.223] | [-0.368, -0.222] | [-0.371, -0.241] | [-0.368, -0.241] | [-0.369, -0.242] | [-0.370, -0.240] |

Baseline Mean (DD % Impact)

| Baseline Mean (DD % Impact) | 4.24 (6.98%) | 4.24 (6.98%) | 4.24 (6.98%) | 4.24 (7.21%) | 4.24 (7.19%) | 4.24 (7.21%) | 4.24 (7.19%) |

Baseline Mean (South) 4.16

| City of Residence Fixed Effects | Yes | No | Yes | Yes | Yes | Yes | Yes |
| Month of Conception Fixed Effects | No | Yes | Yes | Yes | Yes | Yes | Yes |
| Time Varying Controls (City-Month) | No | No | No | Yes | Yes | Yes | Yes |
| Adjusted R-squared | 0.570 | 0.078 | 0.93 | 0.601 | 0.605 | 0.605 | 0.617 | 0.602 |
| Administrative Records Used | SINASC | SINASC | SINASC | SINASC | SINASC | SINASC | SINASC | SINASC |
| # of City-month observations | 196,376 | 196,376 | 196,376 | 190,423 | 190,423 | 190,423 | 190,423 | 190,423 |

Notes: *** denotes significance at 1 percent, ** at 5 percent, and * at 10 percent level. The dependent variable is the conception rate in the city-month. Conception dates are recovered using information on the last menstruation date, and by subtracting the number of gestational weeks or categories of length of gestation from the exact date of birth. This analysis excludes mothers aged below 12 or older than 49. Outcomes are derived from the SINASC birth records. Conception rates are calculated considering the number of women starting their pregnancy per month per 1,000 women living in the same city. The population of women in the city is derived from DATASUS and is for 2012. Observations are weighted by the number of women in the city in 2012. The city of residence fixed effects cover 5,565 cities. In Column 4 onwards, the temperature controls include the city-month averages (derived from daily data) on temperature (in Celsius), wind speed (in kilometers), total insolation, precipitation (in millimeters), air humidity, maximum temperature (in Celsius) and min temperature (in Celsius). At the foot of each column, the difference-in-difference shows the difference between post and pre-alert impacts relative to earlier non-Zika years (and the corresponding percentage impact relative to the baseline mean). 95% confidence intervals are in brackets. Standard errors are clustered by state throughout.
Table 3: Behavior During Pregnancy

<table>
<thead>
<tr>
<th>Month of Outcome</th>
<th>(1) Pregnancy Test</th>
<th>(2) Ultrasound</th>
<th>(3) Abortion</th>
<th>(4) Abortion</th>
<th>(5) Number of Prenatal Visits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All</td>
<td>Positive</td>
<td>All</td>
<td>Positive</td>
<td>Positive</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May_Jul x Zika (Pre-Alert, 1st Quarter)</td>
<td>5.55***</td>
<td>7.37***</td>
<td>3.22</td>
<td>3.50</td>
<td>3.88</td>
</tr>
<tr>
<td></td>
<td>(1.24)</td>
<td>(1.24)</td>
<td>(5.70)</td>
<td>(6.48)</td>
<td>(4.11)</td>
</tr>
<tr>
<td>Aug_Oct x Zika (Pre-Alert, 2nd Quarter)</td>
<td>5.36***</td>
<td>7.07***</td>
<td>-4.44</td>
<td>-5.48</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>(1.19)</td>
<td>(1.14)</td>
<td>(5.03)</td>
<td>(5.79)</td>
<td>(3.82)</td>
</tr>
<tr>
<td>Nov_Jan x Zika (Post-Alert, 1st Quarter)</td>
<td>4.41**</td>
<td>5.89***</td>
<td>9.92</td>
<td>11.24</td>
<td>5.37</td>
</tr>
<tr>
<td></td>
<td>(1.20)</td>
<td>(1.29)</td>
<td>(6.18)</td>
<td>(6.89)</td>
<td>(3.26)</td>
</tr>
<tr>
<td>Feb_April x Zika (Post-Alert, 2nd Quarter)</td>
<td>5.95**</td>
<td>7.90***</td>
<td>34.80***</td>
<td>39.25***</td>
<td>15.76***</td>
</tr>
<tr>
<td></td>
<td>(1.83)</td>
<td>(2.07)</td>
<td>(4.99)</td>
<td>(5.51)</td>
<td>(3.06)</td>
</tr>
<tr>
<td>Difference-in-Difference (Post-Alert 2nd Quarter - Pre-Alert 2nd Quarter)</td>
<td>.589</td>
<td>.833</td>
<td>39.2***</td>
<td>44.7***</td>
<td>14.7***</td>
</tr>
<tr>
<td></td>
<td>(.988)</td>
<td>(.34)</td>
<td>(4.93)</td>
<td>(5.32)</td>
<td>(3.26)</td>
</tr>
<tr>
<td>Baseline Mean (DD % Impact)</td>
<td>6.39 (9.22%)</td>
<td>8.46 (9.85%)</td>
<td>248 (15.8%)</td>
<td>283 (15.8%)</td>
<td>164 (9.00%)</td>
</tr>
<tr>
<td>City of Residence Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Month of Event Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Time Varying Controls (City-Month)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Adjusted R-squared</td>
<td>.547</td>
<td>.532</td>
<td>.562</td>
<td>.515</td>
<td>.755</td>
</tr>
<tr>
<td>Administrative Records Used</td>
<td>SIH/SIA</td>
<td>SIH/SIA</td>
<td>SIH/SIA</td>
<td>SIH/SIA</td>
<td>SIH/SIA</td>
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<tr>
<td># of City-month observations</td>
<td>189,535</td>
<td>79,933</td>
<td>189,535</td>
<td>88,873</td>
<td>189,535</td>
</tr>
</tbody>
</table>

Notes: *** denotes significance at 1 percent, ** at 5 percent, and * at 10 percent level. Outcomes are measured as occurring in the city-month. In Columns 1 to 3, outcomes are derived from the SIH/SIA inpatient-outpatient records. In all Columns, the outcome is defined per 1,000 women conceiving their pregnancy in the same city in the three months prior to the event. Pregnancy dates are recovered using information on the last menstruation date, and by subtracting the number of gestational weeks or categories of length of gestation from the exact date of birth. This analysis excludes mothers aged below 12 or older than 49. Observations are weighted by the population of women in the city in 2012, as derived from DATASUS. For each outcome, the sample in the first Column (“All”) covers all cities, the sample in the second Column (“Positive”) covers those cities that have a strictly positive outcome in at least one month over the sample period. In Column 4 information on abortions is derived from SIM mortality records. This only covers the subset of fetal abortions that have gestation length of at least 20 weeks, birthweight is at least 500 grams and the length of the baby is at least 25 centimeters. The outcome in Column 5 is defined as the average per pregnant women (as measured at the time of birth at the end of the pregnancy), and is derived from SINASC records. The city of residence fixed effects cover 5,565 cities. The temperature controls include the city-month averages (derived from daily data) on temperature (in Celsius), wind speed (in kilometers), total insolation, precipitation (in millimeters), air humidity, maximum temperature (in Celsius) and min temperature (in Celsius). At the foot of each column, the difference-in-difference shows the difference between the second quarter of post and pre-alert impacts relative to earlier non-Zika years (and the corresponding percentage impact relative to the baseline mean). 95% confidence intervals are in brackets. Standard errors are clustered by state throughout.
### Table 4: Birth Outcomes

**Dependent variables:** Rates per 1,000 births in the city-month  
City-month observations, weighed by 2012 city population of women aged 12-49  
Standard errors clustered by state in parentheses

<table>
<thead>
<tr>
<th>Month of Conception</th>
<th>(1) Miscarriage</th>
<th>(2) C-Section Delivery</th>
<th>(3) Premature Delivery (≥1 if &lt; 37 wks)</th>
<th>(4) Low birth weight (&lt; 2500g)</th>
<th>(5) Microcephaly</th>
<th>(6) Other Congenital Malformation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zika, Pre-Alert (β₁)</td>
<td>1.38</td>
<td>-7.42***</td>
<td>-.299</td>
<td>1.75***</td>
<td>.808***</td>
<td>.817***</td>
</tr>
<tr>
<td></td>
<td>(2.86)</td>
<td>(2.49)</td>
<td>(.887)</td>
<td>(.375)</td>
<td>(.166)</td>
<td>(.211)</td>
</tr>
<tr>
<td>Zika, Post-Alert (β₂)</td>
<td>7.12***</td>
<td>-9.86***</td>
<td>1.67**</td>
<td>.675*</td>
<td>-.239</td>
<td>.895***</td>
</tr>
<tr>
<td></td>
<td>(2.54)</td>
<td>(3.02)</td>
<td>(.715)</td>
<td>(.340)</td>
<td>(.271)</td>
<td>(.301)</td>
</tr>
<tr>
<td>Difference-in-Difference</td>
<td>5.73**</td>
<td>-2.44</td>
<td>1.97*</td>
<td>-1.07**</td>
<td>-1.04**</td>
<td>.078</td>
</tr>
<tr>
<td></td>
<td>(2.41)</td>
<td>(2.82)</td>
<td>(.448)</td>
<td>(.107)</td>
<td>(.416)</td>
<td>(.810)</td>
</tr>
<tr>
<td>Baseline Mean (DD % Impact)</td>
<td>139.3 (4.11%)</td>
<td>571 (.427%)</td>
<td>120 (1.64%)</td>
<td>84.5 (1.26%)</td>
<td>.061 (1705%)</td>
<td>7.44 (1.04%)</td>
</tr>
</tbody>
</table>

- **Month of Conception Fixed Effects:** Yes  
- **City of Residence Fixed Effects:** Yes  
- **Time-Varying Controls (City-Month):** Yes  
- **Adjusted R-squared:** .743  
- **Administrative Records Used:** SIH&SIA, SINASC, SINASC, SINASC, SINASC, SINASC  
- **# of City-month observations:** 189,535

**Notes:** *** denotes significance at 1 percent, ** at 5 percent, and * at 10 percent level.  
All outcomes are derived from the SINASC birth records. Month refer to the month of conception.  
Pregnancy dates are recovered using information on the last menstruation date, and by subtracting the number of gestational weeks or categories of length of gestation from the exact date of birth.  
In Column 1 miscarriage types include ectopic, molar pregnancies, spontaneous abortions, abnormal conceptions (ICD codes: O021, O028 and O029), medical abortions (ICD codes: O040 until O049), unspecified abortions (ICD codes: O060 until O069), other abortions (ICD codes: O050 until O059), failed abortions (ICD codes: O070 until O079) and unplanned abortions (ICD codes: N96 and O262). In Column 5, microcephaly at birth is identified from IC-10 code Q02X. This analysis excludes mothers aged below 12 or older than 49. Outcomes are defined as the rate per 1000 births in the city-month. Observations are weighted by the population of women in the city in 2012. The city of residence fixed effects cover 5,565 cities. The temperature controls include the city-month averages (derived from daily data) on temperature (in Celsius), wind speed (in kilometers), total insolation, precipitation (in millimeters), air humidity, maximum temperature (in Celsius) and min temperature (in Celsius). At the foot of each column, the difference-in-difference shows the difference between the post and pre-alert impacts relative to earlier non-Zika years (and the corresponding percentage impact relative to the baseline mean). 95% confidence intervals are in brackets. Standard errors are clustered by state throughout.
### Table 5: Birth Outcomes and Mother Characteristics

**Dependent variables:** Rates per 1,000 births in the city-month  
**City-month observations,** weighed by 2012 city population of women aged 12-49  
**Standard errors clustered by state in parentheses**

<table>
<thead>
<tr>
<th>Month of Conception</th>
<th>(1) C-Section Delivery</th>
<th>(2) Premature (=1 if &lt; 37 wks)</th>
<th>(3) Low birth weight (&lt; 2500g)</th>
<th>(4) Microcephaly</th>
<th>(5) Other Congenital Malformation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zikat, Pre-Alert (β1)</td>
<td>-10.9*** (.232)</td>
<td>.100 (.811)</td>
<td>1.32*** (.374)</td>
<td>.790*** (.159)</td>
<td>.728*** (.215)</td>
</tr>
<tr>
<td>Zikat, Post-Alert (β2)</td>
<td>19.6 (21.0)</td>
<td>-18.6* (9.94)</td>
<td>-3.04 (7.28)</td>
<td>1.11 (1.81)</td>
<td>-7.02 (5.98)</td>
</tr>
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<td>Difference-in-Difference</td>
<td>30.6 (20.5)</td>
<td>-18.7* (9.77)</td>
<td>-4.36 (7.27)</td>
<td>.321 (1.75)</td>
<td>-7.75 (6.10)</td>
</tr>
<tr>
<td>Baseline Mean (DD % Impact)</td>
<td>571 (5.35%)</td>
<td>120 (15.5%)</td>
<td>84.5 (5.15%)</td>
<td>.061 (526%)</td>
<td>7.44 (104.1%)</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>City of Residence Fixed Effects</td>
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<td>Yes</td>
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<td>SINASC</td>
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<tr>
<td># of City-month observations</td>
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<td>189.461</td>
<td>189.461</td>
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</tr>
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</table>

**Notes:** *** denotes significance at 1 percent, ** at 5 percent, and * at 10 percent level. All outcomes are derived from the SINASC birth records. Month refer to the month of conception. Pregnancy dates are recovered using information on the last menstruation date, and by subtracting the number of gestational weeks or categories of length of gestation from the exact date of birth. In Column 4, microcephaly at birth is identified from IC-10 code Q02X. This analysis excludes mothers aged below 12 or older than 49. Outcomes are defined as the rate per 1000 births in the city-month. Observations are weighted by the population of women in the city in 2012. The city of residence fixed effects cover 5,565 cities. The temperature controls include the city-month averages (derived from daily data) on temperature (in Celsius), wind speed (in kilometers), total insolation, precipitation (in millimeters), air humidity, maximum temperature (in Celsius) and min temperature (in Celsius). In each Column, we control for the percentage of pregnancies to teen mothers in the city-month, the percentage to non-white mothers, the percentage to mothers with basic education, the average age of mothers, and interactions of each with (Post-alert x Zika interaction). At the foot of each column, the difference-in-difference shows the difference between the post and pre-alert impacts relative to earlier non-Zika years (and the corresponding percentage impact relative to the baseline mean). 95% confidence intervals are in brackets. Standard errors are clustered by state throughout.
B. Spatial Incidence of Microcephaly Cases

Panel A shows the number of microcephaly cases per region of birth from January 2014 until December 2016. The information of congenital malformation was generated using the international disease code Q02 referring to new borns with microcephaly. On the 11th November 2015 the Brazilian government officially announced the association between the upsurge of Zika and microcephaly in Northeastern Brazil. This is indicated by the vertical dashed line. Panel B shows the rate of microcephaly in each city per 100,000 births during 2015 and 2016.

Notes: Panel A shows the number of microcephaly cases per region of birth from January 2014 until December 2016. The information of congenital malformation was generated using the international disease code Q02 referring to new borns with microcephaly. On the 11th November 2015 the Brazilian government officially announced the association between the upsurge of Zika and microcephaly in Northeastern Brazil. This is indicated by the vertical dashed line. Panel B shows the rate of microcephaly in each city per 100,000 births during 2015 and 2016.
Figure 2: Public Awareness

A. Media Mention of 'Microcephaly' in Three Leading Newspapers

Panel A shows media coverage of the word 'microcephaly' ("Microcefalia" in Brazilian Portuguese) appears in the printed and online editions of three leading newspapers in Brazil: Folha de Sao Paulo, O Globo and Estado. Regional editions were excluded from the search. On the 11th November 2015 the Brazilian government officially announced the association between the upsurge of Zika and microcephaly in Northeastern Brazil. This is indicated by the vertical dashed line.

B. Google Searches for Zika, Microcephaly, Repellent

Panel B presents the intensity of Google searches for the following words: "Zika", "Microcephaly" and "Repellent" within Brazil over time. The dark gray line represents "Zika Virus", "Sintomas da Zika" and "Zika" to account for misspelling. Similarly, the time series for "Microcephaly" refers to "Microcefalia" or "Microcefalia Zika", as translated from Brazilian Portuguese. Searches of "Repellent" indicates searches of "Repelente" (in Portuguese). Panel C presents a map of the spatial variation of Google searches of "Zika" from July 2013 until July 2018. Incidence is show per state, the lowest geographical level available.

Notes: Panel A shows media coverage of the word ‘microcephaly’ ("Microcefalia" in Brazilian Portuguese) appears in the printed and online editions of three leading newspapers in Brazil: Folha de Sao Paulo, O Globo and Estado. Regional editions were excluded from the search. On the 11th November 2015 the Brazilian government officially announced the association between the upsurge of Zika and microcephaly in Northeastern Brazil. This is indicated by the vertical dashed line. Panel B presents the intensity of Google searches for the following words: "Zika", "Microcephaly" and "Repellent" within Brazil over time. The dark gray line represents "Zika Virus", "Sintomas da Zika" and "Zika" to account for misspelling. Similarly, the time series for "Microcephaly" refers to "Microcefalia" or "Microcefalia Zika", as translated from Brazilian Portuguese. Searches of "Repellent" indicates searches of "Repelente" (in Portuguese). Panel C presents a map of the spatial variation of Google searches of "Zika" from July 2013 until July 2018. Incidence is show per state, the lowest geographical level available.
Figure 3: Doctors’ Awareness

A. Incidence of "Microcephaly" Written in Doctor’s Notes

Notes: All data is constructed from information derived from the Sistema de Informação de Agravos de Notificação (SINAN), from January 2014 until December 2015. Doctor’s notes are from doctors treating patients going to the hospital showing symptoms similar to dengue or patients suspected to have dengue. Hence confirmed and suspected cases are included in the sample. In each Panel, the x-axis shows the month of appointment and y-axis is the number of times certain words appear in doctor’s notes per 1000 dengue cases. On the 11th November 2015 the Brazilian government officially announced the association between the upsurge of Zika and microcephaly in Northeastern Brazil. This is indicated by the vertical dashed line in each Panel. Nov-bef refers to appointments from the 1st to 10th of November. Nov-af refers to appointments from the 11th to 30th of November 2015. Panel A shows doctor’s notes for “Microcefalia” (Microcephaly, in Portuguese); Panel B indicates the frequency of “Zika”, “Zica” or “Zica Virus” in doctor’s notes; Panel C indicates the frequency of “Gestantes” (pregnant women in Portuguese) in doctor’s notes.
On the 11th November 2015 the Brazilian government officially announced the association between the upsurge of Zika and microcephaly in Northeastern Brazil. This is indicated by the vertical dashed line from Panels A to C. Panel A presents weekly changes in conception dates from the 33th to the 57th week of 2013/14 and 2015/16; 12 weeks before/after Zika Alert on the 45th week of 2015. Dates on x-axis on Panel A indicate the last day of each week. Conception dates are recovered using information on the last menstruation date, and by subtracting the number of gestational weeks or categories of length of gestation from the exact date of birth. This analysis excludes mothers aged below 12 or older than 49. Outcomes are derived from the SINASC birth records. Conception rates are calculated considering the number of women starting their pregnancy per month per 1,000 women living in the same city. The population of women in the city is derived from DATASUS and is for 2012. Observations are weighted by the number of women in the city in 2012. Panels B and C plot difference-in-difference coefficients from 15 exclusive dummies on months since the Zika alert. Month -6 (six months prior to the alert being issued in November 2015) is used as a baseline. The dependent variable is the log conception rate in the city-month. The x-axis in Panels B and C represent the number of months before and after the alert. The y-axis plots the coefficient and the associated 90% confidence interval, where standard errors are clustered by state in the underlying regression.
Figure 5: Heterogeneous Responses
A. By Race, Marital Status and Education

B. By Age and Socio-Economic Status

Notes: The Panels show the impacts of the Zika alert on conception rates among different subgroups, and the associated 90% confidence intervals. Non-white women are those reporting their race to be Black, Yellow, Parda and Native. The categories for mother's education include women with basic education (up to 7 years of schooling); high-school education includes women with between 8 and 11 years of schooling; diploma refers to women with more than 12 years of schooling. On pregnancy numbers, first includes mothers in their first pregnancy and the second refers to mothers in their second or later pregnancy. The dependent variable throughout is the log conception rate in the city-month for a given subgroup. Conception dates are recovered using information on the last menstruation date, and by subtracting the number of gestational weeks or categories of length of gestation from the exact date of birth. This analysis excludes mothers aged below 12 or older than 49. Outcomes are derived from the SINASC birth records. Conception rates are calculated considering the number of women starting their pregnancy per month per 1,000 women living in the same city. The population of women in the city is derived from DATASUS and is for 2012. Observations are weighted by the number of women in the city in 2012.
Figure 6: Relative Risk of Microcephaly
A. By Race, Marital Status and Education

B. By Age and Socio-Economic Status

Notes: Figures A and B present the relative risk of having a child with microcephaly among different subgroups of mothers and their associated 95% confidence intervals. Pre-Alert periods in blue indicate (6 months before Zika Alert and Post Alert in red indicates 6 months after Zika Alert on 11 November 2015. These figures exclude mothers aged below 12 or older than 49. Relative risk ratios are measured by the share of all microcephaly cases in the specific group divided by the share of all births in the same group. If the risk of having a child with microcephaly is random across groups, the relative risk ratio should be near to one and that is represented by the horizontal dashed line. The "Non-White" group in Figure A comprehends women reporting their race to be Black, Yellow, Parda and Native. The categories for mother's education include women with basic education (up to 7 years of schooling); high-school education includes women with between 8 and 11 years of schooling; diploma refers to women with more than 12 years of schooling. We consider "Young" as women between 12 and 34 years old and "Old" as women between 35 and 49 years old. The socio-economic categories "Low SES" are women with basic education and "High SES" are women with a Diploma. The incidence of microcephaly and number of births are derived from the SINASC and the population of women in each group comes from DATASUS and is for 2012.
Notes: Panels A and B show the impacts of the Zika alert on congenital malformations and the corresponding 95% confidence intervals (where standard errors are clustered at state level on the underlying difference-in-difference regression). Light blue bars represent the Pre-Alert coefficient (beta 1), light red bars plot the Post-Alert coefficient (beta 2) and the light yellow bars are the difference-in-difference coefficient (beta 2 - beta 1). These estimates consider the number of congenital malformations (by month of conception) according to SINASC birth records and excludes mothers aged below 12 or older than 49. Observations are weighted by the number of women in the city in 2012. In Panel A, the group “Microcephaly” shows the number of births with ICD code Q02, “Ankyloglossia” refers to ICD code Q381, “Hypoplasia” refers to ICD code Q270, Macrocephaly refers to ICD code Q75.3 and Malformations in the brain refers to ICD codes Q040 until Q049. In Panel B, “Polymicrogyria” refers to ICD code Q043, “Schizencephaly” refers to ICD code Q046, “Dextrocardia” refers to ICD code Q240, “Dolichocephalics” refers to ICD code Q67.2, “Osteomuscular” refers to other congenital deformities indicated by ICD code Q688, “Arthrogripose” has ICD code Q743, congenital “Cataract” refers to ICD code Q120, “Microphthalmia” refers to ICD code Q112, and malformations in the eye refer to ICD codes between Q130 and Q159.
Notes: Both Panels presents the monthly difference-in-difference coefficients of microcephaly cases. Panel A does so for all of Brazil, Panel B plots the coefficients for North East and South East regions only. The dependent variable is the rate of microcephaly cases (IDC "Q02") on live births in SINASC per 1000 births in the city-month. The vertical line illustrates the Zika alert on 11th November 2015 which represents when the Brazilian government officially announced the association between the upsurge of Zika and microcephaly in Northeastern Brazil. The regressions used month -16 (sixteen months prior to the alert) as baseline. The x-axis represents the number of months before and after the alert. The y-axis plots the coefficient and the associated 90% confidence interval. Standard errors are clustered by state in the underlying regression.
### Table A1: Hospital Admission Rates

Dependent variable: Hospital admissions per 1000 population, or pregnant women
City-month observations, weighed by 2012 city population (Columns 1-2), by 2012 population of women aged 12 to 49 (Columns 3-4)
Standard errors clustered by state in parentheses

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<thead>
<tr>
<th></th>
<th>Population</th>
<th>Pregnant Women</th>
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<td>(1) Baseline</td>
<td>(2) State Specific Trends</td>
<td>(3) Baseline</td>
<td>(4) State Specific Trends</td>
<td></td>
</tr>
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<td>Zika, Pre-Alert (β1)</td>
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<td>.176</td>
<td>.357</td>
<td>-3.55*</td>
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<td></td>
<td>(2.43)</td>
<td>(2.47)</td>
<td>(3.55)</td>
<td>(3.99)</td>
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<tr>
<td>Zika, Post-Alert (β2)</td>
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<td>-1.00</td>
<td>-.771**</td>
<td>-1.51***</td>
<td>(.365)</td>
</tr>
<tr>
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<td>(3.55)</td>
<td>(3.99)</td>
<td>(3.55)</td>
<td>(3.99)</td>
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</tr>
<tr>
<td>Difference-in-Difference</td>
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<td>-1.18</td>
<td>-1.12***</td>
<td>-1.15***</td>
<td>(.304)</td>
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<td>(1.85)</td>
<td>(1.88)</td>
<td>(1.85)</td>
<td>(1.88)</td>
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<tr>
<td>Baseline Mean (DD % Impact)</td>
<td>114 (.894%)</td>
<td>114 (1.03%)</td>
<td>16.2 (6.91%)</td>
<td>16.2 (7.09%)</td>
<td></td>
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<td>City of Residence Fixed Effects</td>
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<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Month Fixed Effects</td>
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<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
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<td>Time Varying Controls (City-Month)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>State Specific Linear Time Trend</td>
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<td>Yes</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>Adjusted R-squared</td>
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<td>.731</td>
<td>.743</td>
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<td>SIA &amp; SIH</td>
<td>SIA &amp; SIH</td>
<td>SIA &amp; SIH</td>
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<td># of City-month observations</td>
<td>189,578</td>
<td>189,578</td>
<td>189,578</td>
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**Notes:** *** indicates significance at 1 percent, ** at 5 percent, and * at 10 percent level. In Columns 1 and 2, the dependent variable is the patient admission rate in the city-month. Patient admission rates are calculated by the number of all patients in SIA & SIH per month per 1,000 population living in the City. In Columns 3 and 4, the dependent variable considers pregnant women admissions rates in the city-month. As SIA and SIH do not provide if the patient is expecting, we measure the number of pregnant women admitted in the hospital by adding up the number of admissions for: neonatal triage (id 0201020050), pregnancy test (id 0214010066), ultrasound (id 0205010059, 0205020143 and 0205020151), prenatal visit (ids 0301010110, 0301010234, 0801010012, 0801010020), treating eclampsia (Ids 0303100028), treating congenital malformations (ids 0303110074, 0303110015, 0303110023, 0303110104, 0303160020, 0303110015, 0303110040, 0303110066, 0303110074), treating disturbances generated during the pregnancy (ids 0303160039, 0303160055, 0303100036, 0411020056), emptying the womb after abortion (Id 0409060070), ectopic pregnancy (ICD-10 O000, O001, O002, O008, O009), molar pregnancy (ICD-10 O010, O011,O019, O020), abnormal conception (ICD-10 O021,O028, O029), spontaneous abortion (ICD-10 from O030 to O039), legal or clinical abortion (ICD-10 from O040 until O049), other types of abortion (ICD-10 from O050 until O059), unspecified abortion (ICD-10 from O060 to O069), failed abortion (ICD-10 from O070 to O079), usual abortion (ICD-10 N96 and O262), moderate pre-eclampsia (ICD-10 O140), non-specified pre-eclampsia (ICD-10 O149), severe pre-eclampsia (ICD-10 O141), eclampsia during pregnancy (ICD-10 O150, O151, O152, O159), counselling for contraceptives (ICD-10 Z300, Z314, Z316, Z318, Z319), treating abortion (ICD-10 O200), hypertension during pregnancy (ICD-10 O100), assisting pregnant women (ICD-10 O350, O359, O361, O362, O363, O366, O369), and birth labor (ICD-10 O600, O601, O602, O610, O623). The observations in Columns 1 and 2 weighted by the total population in the city while in Columns 3 and 4 we weight by the number of women in the city in 2012. The city of residence fixed effects cover 5,565 cities. The temperature controls include the city-month averages (derived from daily data) on temperature (in Celsius), wind speed (in kilometers), total insolation (in millimeters), air humidity, maximum temperature (in Celsius) and min temperature (in Celsius). At the foot of each column, the difference-in-difference shows the difference between post and pre-alert impacts relative to earlier non-Zika years (and the corresponding percentage impact relative to the baseline mean). 95% confidence intervals are in brackets. Standard errors are clustered by state throughout.
### Table A2: Robustness Checks

**Dependent variable, Columns 1 to 7: Pregnancy rate**

**Dependent variable, Columns 8 to 10: Share of births in which mother’s city of residence and city of birth differ**

City-month observations, weighed by 2012 city population of women aged 12-49

<table>
<thead>
<tr>
<th>(1) Baseline</th>
<th>(2) Drop Month Fixed Effects</th>
<th>(3) Unweighted</th>
<th>(4) Drop Smaller Cities</th>
<th>(5) Include 2012 Data</th>
<th>(6) Alternative Numerator</th>
<th>(7) Health Personnel</th>
<th>(8) City of Residence and Birth Differ</th>
<th>(9) City of Residence and Birth Differ, Abortion Available</th>
<th>(10) City of Residence and Birth Differ, City Ultrasound Available</th>
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<tbody>
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<td>Zika, Pre-Alert ($\beta_1$)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>-0.013</td>
<td>0.002</td>
<td>0.004</td>
<td>-0.013</td>
<td>0.048*</td>
<td>-0.010</td>
<td>-0.006</td>
<td>0.008**</td>
<td>0.017</td>
<td>-0.015</td>
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<td>(0.019)</td>
<td>(0.018)</td>
<td>(0.012)</td>
<td>(0.020)</td>
<td>(0.021)</td>
<td>(0.022)</td>
<td>(0.018)</td>
<td>(0.002)</td>
<td>(0.020)</td>
<td>(0.020)</td>
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<tr>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.319***</td>
<td>-0.303***</td>
<td>-0.267***</td>
<td>-0.321***</td>
<td>-0.255***</td>
<td>-0.350***</td>
<td>-0.308***</td>
<td>0.005**</td>
<td>-0.324***</td>
<td>-0.328***</td>
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<tr>
<td>(0.032)</td>
<td>(0.031)</td>
<td>(0.035)</td>
<td>(0.033)</td>
<td>(0.029)</td>
<td>(0.035)</td>
<td>(0.032)</td>
<td>(0.002)</td>
<td>(0.030)</td>
<td>(0.033)</td>
</tr>
</tbody>
</table>

**Difference-in-Difference**

| -0.306*** | -0.305*** | -0.270*** | -0.308*** | -0.303*** | -0.340*** | -0.302*** | 0.001 | -0.306*** | -0.312*** |
| (0.032) | (0.030) | (0.035) | (0.032) | (0.030) | (0.035) | (0.031) | (0.001) | (0.030) | (0.033) |

**Baseline Mean (DD % Impact)**

| 4.24 (7.21%) | 4.24 (7.19%) | 4.09 (6.60%) | 4.25 (7.24%) | 4.18 (7.24%) | 4.53 (7.50%) | 4.24 (7.12%) | 0.309 (0.323%) | 4.26 (7.18%) | 4.25 (7.34%) |

**Notes:** *** denotes significance at 1 percent, ** at 5 percent, and * at 10 percent level. The dependent variable in Columns 1 to 7 is the conception rate in the city-month. Conception dates are recovered using information on the last menstruation date, and by subtracting the number of gestational weeks or categories of length of gestation from the exact date of birth. This analysis excludes mothers aged below 12 or older than 49. Outcomes are derived from the SINASC birth records. Conception rates are calculated considering the number of women starting their pregnancy per month per 1,000 women living in the same city (except in Column 6). The population of women in the city is derived from DATASUS and is for 2012. Observations are weighted by the number of women in the city in 2012 (except in Column 3). Column 2 drops month fixed effects. Column 3 does not weight observations. Column 4 drops cities that ever have zero conceptions in a month. Column 5 additionally includes data on conceptions from 2012. Column 6 uses an alternative denominator for conception rates: it subtracts from the number of women in the city the number of women that started their pregnancies in last 8 months (i.e. t, t-1 until t-8 months), and the number of women giving birth during months t, t-1 until t-8. Column 7 adds controls for the number of health professionals per city-month. The CNES data identifies three types of health workers using unique identification codes: “Health Agents to fight Epidemics” (Codes = 515105, 352210, 515140 and 5151F1), “Health Workers for Sanitary Visits” (Code = 515120) and professionals working for the Brazilian National Health System and in the private health care sector. Each code is from the official Brazilian Classification of Occupations and is established by the Ministry of Labor (CBO). In Columns 8 to 10 the outcome is the share of women giving birth in the city-period whose city of residence and city of birth differ. The city of residence fixed effects cover 5,565 cities. The temperature controls include the city-month averages (derived from daily data) on temperature (in Celsius), wind speed (in kilometers), total insolation, precipitation (in millimeters), air humidity, maximum temperature (in Celsius) and min temperature (in Celsius). At the foot of each column, the difference-in-difference shows the difference between post and pre-alert impacts relative to earlier non-Zika years (and the corresponding percentage impact relative to the baseline mean). 95% confidence intervals are in brackets. Standard errors are clustered by state throughout.
## Table A3: Birth Outcomes by the Availability of Abortions, Ultrasounds

**Dependent variables:** Rates per 1,000 births in the city-month. City-month observations, weighted by 2012 city population of women aged 12-49. Standard errors clustered by state in parentheses.

### Month of Conception

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<th>Abortion Available</th>
<th>No Abortion Available</th>
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<td>Zika, Pre-Alert (β)</td>
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<td>-1.28***</td>
<td>-1.95**</td>
<td>-1.56***</td>
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<tr>
<td></td>
<td>(.425)</td>
<td>(.408)</td>
<td>(.233)</td>
<td>(.333)</td>
</tr>
<tr>
<td>Zika, Post-Alert (β)</td>
<td>.207</td>
<td>-.473*</td>
<td>-.171</td>
<td>-.603*</td>
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<td></td>
<td>(.278)</td>
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<td>(.242)</td>
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### Baseline Mean (DD % Impact)

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<th>Yes</th>
<th>Yes</th>
<th>Yes</th>
<th>Yes</th>
<th>Yes</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>City of Residence Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Time-Varying Controls (City-Month)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Adjusted R-squared</td>
<td>.877**</td>
<td>.323</td>
<td>.872***</td>
<td>.530**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Administrative Records Used</td>
<td>SINASC</td>
<td>SINASC</td>
<td>SINASC</td>
<td>SINASC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### # of City-month observations

| 88,950 | 101,473 | 76,557 | 113,866 |

### Notes:

*** denotes significance at 1 percent, ** at 5 percent, and * at 10 percent level. All outcomes are derived from the SINASC birth records. Month refer to the month of conception. Pregnancy dates are recovered using information on the last menstruation date, and by subtracting the number of gestational weeks or categories of length of gestation from the exact date of birth. In Panel C, microcephaly at birth is identified from IC-10 code Q02X. This analysis excludes mothers aged below 12 or older than 49. Outcomes are defined as the rate per 1000 births in the city-month. Observations are weighted by the population of women in the city in 2012. The city of residence fixed effects cover 5,565 cities. The temperature controls include the city-month averages (derived from daily data) on temperature (in Celsius), wind speed (in kilometers), total insolation, precipitation (in millimeters), air humidity, maximum temperature (in Celsius) and min temperature (in Celsius). At the foot of each column, the difference-in-difference shows the difference between the post and pre-alert impacts relative to earlier non-Zika years (and the corresponding percentage impact relative to the baseline mean). 95% confidence intervals are in brackets. Standard errors are clustered by state throughout.
### Table A4: Demographic Characteristics of Mothers

#### Dependent variables: Percentages or averages in the city-month

City-month observations, weighed by 2012 city population of women aged 12-49

Standard errors clustered by state in parentheses

<table>
<thead>
<tr>
<th>Month of Conception</th>
<th>(1) % of Teenage mothers</th>
<th>(2) % of Non-White Mothers</th>
<th>(3) % of Missing Fathers Age</th>
<th>(4) % with Basic Education</th>
<th>(5) Average Mothers' Age (in years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zika, Pre-Alert ($\beta_1$)</td>
<td>-.009*** (.001)</td>
<td>.037*** (.005)</td>
<td>.007*** (.002)</td>
<td>-.029*** (.002)</td>
<td>.259*** (.012)</td>
</tr>
<tr>
<td>Zika, Post-Alert ($\beta_2$)</td>
<td>-.005*** (.001)</td>
<td>.039*** (.006)</td>
<td>.012*** (.002)</td>
<td>-.021*** (.002)</td>
<td>.084** (.031)</td>
</tr>
<tr>
<td>Difference-in-Difference</td>
<td>.003*** (.000)</td>
<td>.002 (.004)</td>
<td>.004*** (.001)</td>
<td>.007*** (.001)</td>
<td>-.177*** (.023)</td>
</tr>
</tbody>
</table>

Baseline Mean (DD % Impact)

| | .132 (2.27%) | .527 (.379%) | .616 (.649%) | .228 (3.07%) | 26.3 (.672%) |

City of Residence Fixed Effects

Yes Yes Yes Yes Yes

Month of Conception Fixed Effects

Yes Yes Yes Yes Yes

Time Varying Controls (City-Month)

Yes Yes Yes Yes Yes

Adjusted R-squared

.345 .900 .939 .651 .572

Administrative Records Used

SINASC SINASC SINASC SINASC SINASC

# of City-month observations

190,423 190,423 189,620 190,230 190,423

**Notes:** *** denotes significance at 1 percent, ** at 5 percent, and * at 10 percent level. All outcomes are derived from the SINASC birth records. Month refer to the month of conception. This analysis excludes mothers aged below 12 or older than 49. Outcomes in columns 1 to 4 are defined as the rate per 1000 conception in the city-month (and in Column 5 it is the average age of mothers conceiving in the city-month). Observations are weighted by the population of women in the city in 2012. The city of residence fixed effects cover 5,565 cities. The temperature controls include the city-month averages (derived from daily data) on temperature (in Celsius), wind speed (in kilometers), total insolation, precipitation (in millimeters), air humidity, maximum temperature (in Celsius) and min temperature (in Celsius). At the foot of each column, the difference-in-difference shows the difference between the post and pre-alert impacts relative to earlier non-Zika years (and the corresponding percentage impact relative to the baseline mean). 95% confidence intervals are in brackets. Standard errors are clustered by state throughout.
Table A5: Health Care Personnel Behavior
City-month observations, weighed by 2012 city population of women aged 12-49
Standard errors clustered by state in parentheses

<table>
<thead>
<tr>
<th>Month of Outcome</th>
<th>(1) Dengue Tests Administered to Pregnant Women</th>
<th>(2) Negative Dengue Test Results in Pregnant Women</th>
<th>(3) Inconclusive Dengue Test Results in Pregnant Women</th>
<th>(4) Diagnosed Cases of Zika</th>
<th>(5) Potential Cases of Zika</th>
<th>(6) Counseling on Contraception</th>
<th>(7) Cases of Eclampsia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zika, Pre-Alert (β₁)</td>
<td>.017 (.017)</td>
<td>.018 (.017)</td>
<td>.000 (.001)</td>
<td>.024** (.011)</td>
<td>.007* (.004)</td>
<td>.003 (.002)</td>
<td>.266 (.961)</td>
</tr>
<tr>
<td>Zika, Post-Alert (β₂)</td>
<td>.164* (.088)</td>
<td>.546*** (.077)</td>
<td>.016*** (.003)</td>
<td>.200*** (.056)</td>
<td>.009** (.004)</td>
<td>.001 (.001)</td>
<td>1.07 (.401)</td>
</tr>
<tr>
<td>Difference-in-Difference</td>
<td>.147* (.073)</td>
<td>.527*** (.073)</td>
<td>.016*** (.003)</td>
<td>.176*** (.053)</td>
<td>.002 (.001)</td>
<td>-.002 (.001)</td>
<td>.805 (.101)</td>
</tr>
<tr>
<td>Baseline Mean (DD % Impact)</td>
<td>.059 (249%)</td>
<td>.060 (878%)</td>
<td>.001 (1600%)</td>
<td>.012 (1466%)</td>
<td>.009 (22.2%)</td>
<td>.001 (200%)</td>
<td>33.0 (2.43%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rate Definition</th>
<th>Conceptions in the Previous 8 Months</th>
<th>Conceptions in the Previous 8 Months</th>
<th>Conceptions in the Previous 8 Months</th>
<th>100,000 population</th>
<th>100,000 population</th>
<th>Per 1000 Women</th>
<th>Conceptions in the Previous 8 city-months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Month of Event Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>City of Residence Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Time Varying Controls (City-Month)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Adjusted R-squared</td>
<td>.051</td>
<td>.088</td>
<td>.002</td>
<td>.027</td>
<td>.367</td>
<td>.232</td>
<td>.791</td>
</tr>
<tr>
<td>Administrative Records Used</td>
<td>SINAN</td>
<td>SINAN</td>
<td>SINAN</td>
<td>SIH/SIA</td>
<td>SIH/SIA</td>
<td>SIH/SIA</td>
<td>SIH/SIA</td>
</tr>
<tr>
<td># of City-month observations</td>
<td>97,059</td>
<td>97,059</td>
<td>97,059</td>
<td>193,331</td>
<td>193,331</td>
<td>193,331</td>
<td>189,528</td>
</tr>
</tbody>
</table>

Notes: *** denotes significance at 1 percent, ** at 5 percent, and * at 10 percent level. The outcomes in Columns 1 to 3 are derived from the SINAN dengue database. The outcomes in Columns 4 onwards are derived from SIH/SIA inpatient-outpatient records. Months refers to the month of the outcome. In Columns 1 to 3 and Column 7, rates are defined as per 1000 conceptions that occurred in the city in the previous eight months. Conception dates are recovered using information on the last menstruation date, and by subtracting the number of gestational weeks or categories of length of gestation from the exact date of birth. This analysis excludes mothers aged below 12 or older than 49. In Columns 4 and 5 the rates are defined per 100,000 of the city population. In Column 6 the rates is defined per 1000 women in the city. In Column 1, the ‘Dengue Tests’ derived from the SINAN data relates to the application of Soro, Elisa, Viral isolation, Reverse Transcriptase PCR, Histopathology and immunohistochemistry in patients. In Column 4, Zika cases are identified in the SIH/SIA records using the primary and secondary ICD-10 code A92.8. In Column 5 cases of undiagnosed Zika refer to cases where a doctor has performed tests for dengue (Procedure Id: 0213010119, 021301030, 0213010674, 0214010120), yellow fever (Procedure Id: 0213010127, 0213010623, 0213010348, 0213010658, 0213010682) and chikungunya (Procedure Id: 0214010139) (all diseases transmitted by Aedes aegypti), but could not diagnose any of these. Column 6 on Counselling on Contraception uses the diagnosis Z300 described as General Counselling on Contraceptives. Observations are weighted by the population of women in the city in 2012, as derived from DATASUS. The city of residence fixed effects cover 5,565 cities. The temperature controls include the city-month averages (derived from daily data) on temperature (in Celsius), wind speed (in kilometers), total insolation, precipitation (in millimeters), air humidity, maximum temperature (in Celsius) and min temperature (in Celsius). At the foot of each column, the difference-in-difference shows the difference between the post and pre-alert impacts relative to earlier per-epidemic years (and the corresponding percentage impact relative to the baseline mean). 95% confidence intervals are in brackets. Standard errors are clustered by state throughout.
Table A6: Regional Variation in the Administration of Dengue Tests

City-month observations, weighed by 2012 city population of women aged 12-49
Standard errors clustered by state in parentheses

<table>
<thead>
<tr>
<th>Month of Outcome</th>
<th>(1) Dengue Tests Administered to Pregnant Women</th>
<th>(2) Negative Dengue Test Results in Pregnant Women</th>
<th>(3) Inconclusive Dengue Test Results in Pregnant Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zika, Pre-Alert ($\beta_1$)</td>
<td>.016</td>
<td>.006</td>
<td>-.000</td>
</tr>
<tr>
<td></td>
<td>(.017)</td>
<td>(.016)</td>
<td>(.001)</td>
</tr>
<tr>
<td>Zika, Post-Alert x North East</td>
<td>.063</td>
<td>.520**</td>
<td>.017*</td>
</tr>
<tr>
<td></td>
<td>(.047)</td>
<td>(.198)</td>
<td>(.009)</td>
</tr>
<tr>
<td>Zika, Post-Alert x North</td>
<td>.077**</td>
<td>.376***</td>
<td>.014**</td>
</tr>
<tr>
<td></td>
<td>(.031)</td>
<td>(.112)</td>
<td>(.007)</td>
</tr>
<tr>
<td>Zika, Post-Alert x South East</td>
<td>.195</td>
<td>.530***</td>
<td>.018***</td>
</tr>
<tr>
<td></td>
<td>(.165)</td>
<td>(.046)</td>
<td>(.005)</td>
</tr>
<tr>
<td>Zika, Post-Alert x Centre West</td>
<td>.156***</td>
<td>.450***</td>
<td>.014**</td>
</tr>
<tr>
<td></td>
<td>(.044)</td>
<td>(.104)</td>
<td>(.006)</td>
</tr>
<tr>
<td>Zika, Post-Alert x South</td>
<td>[omitted]</td>
<td>[omitted]</td>
<td>[omitted]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rate Definition</th>
<th>Conceptions in the Previous 8 Months</th>
<th>Conceptions in the Previous 8 Months</th>
<th>Conceptions in the Previous 8 Months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Month of Event Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>City of Residence Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Time Varying Controls (City-Month)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Adjusted R-squared</td>
<td>.050</td>
<td>.083</td>
<td>.002</td>
</tr>
<tr>
<td>Administrative Records Used</td>
<td>SINAN</td>
<td>SINAN</td>
<td>SINAN</td>
</tr>
<tr>
<td># of City-month observations</td>
<td>97,059</td>
<td>97,059</td>
<td>97,059</td>
</tr>
</tbody>
</table>

Notes: *** denotes significance at 1 percent, ** at 5 percent, and * at 10 percent level. The outcomes in Columns 1 to 3 are derived from the SINAN dengue database. Rates are defined as per 1000 conceptions that occurred in the city in the previous eight months. Pregnancy dates are recovered using information on the last menstruation date, and by subtracting the number of gestational weeks or categories of length of gestation from the exact date of birth. This analysis excludes mothers aged below 12 or older than 49. In Column 1, the 'Dengue Tests' derived from the SINAN data relates to the application of Soro, Elisa, Viral isolation, Reverse Transcrptase PCR, Histopathology and immunohistochemistry in patients. Observations are weighted by the population of women in the city in 2012, as derived from DATASUS. The city of residence fixed effects cover 5,565 cities. The temperature controls include the city-month averages (derived from daily data) on temperature (in Celsius), wind speed (in kilometers), total insolation, precipitation (in millimeters), air humidity, maximum temperature (in Celsius) and min temperature (in Celsius). Standard errors are clustered by state throughout.
**Figure A1: Dengue**

A. SINAN Records for Dengue (ICD = A91)

B. Spatial Variation in Dengue Incidence

C. Google Searches for “Dengue”

D. Spatial Variation in Google Searches for Dengue

**Notes:** The time series in suspected or confirmed dengue cases is shown in Panel A. Panel B maps the incidence of dengue per 10,000 people living in cities, for suspected or confirmed cases during 2015 and 2016. Panel C shows the intensity of Google searches for “Dengue” and Panel D presents the spatial variation of google searches for “Dengue”. Panels C and D consider Google searches from 1st January 2013 until 1 January 2018. The y-axis in Panel C is a Google-generated index that equals zero when “Dengue” reaches its lowest search level, and is equal to 100 when it reaches its highest search incidence.
Figure A2: Administration of Dengue Tests to Pregnant Women, Dynamics

A. Dengue Tests, by Week

Panel A shows weekly changes in the rate of dengue tests on pregnant women from the 39th to the 51st week of 2013/14 and 2015/16; 6 weeks before/after Zika Alert on the 45th week of 2015. These rates are calculated by the number of dengue tests on pregnant women in SINAN, or cases of Zika in SIA/SIH, relative to 1000 conceptions in the previous 8 city-months according to SINASC. The vertical dashed line indicates 11th November 2015, when Brazilian authorities officially announced the association between the upsurge of Zika and microcephaly in Northeastern Brazil. The dates on the x-axis on Figure A indicate the last day of each week. Panel B plots 14 monthly Difference-in-Difference coefficients since Zika Alert. The dependent variable is the incidence of dengue tests to pregnant women from SINAN in the city-month. This outcome is measured in the date of outcome rather than in the date of conception, as in the previous tables. The vertical dashed line indicates the Zika Alert on 11th November 2015, when the Brazilian government officially announced the association between the upsurge of Zika and microcephaly in Northeastern Brazil. The y-axis represents the number of months before and after this alert. Month -6 (i.e. six months prior to the alert) is used as a baseline. The y-axis plots the coefficients and their associated 90% confidence intervals (standard errors are clustered by state). Observations are weighted by the number of women in the city in 2012.

Notes: Panel A shows weekly changes in the rate of dengue tests on pregnant women from the 39th to the 51st week of 2013/14 and 2015/16; 6 weeks before/after Zika Alert on the 45th week of 2015. These rates are calculated by the number of dengue tests on pregnant women in SINAN, or cases of Zika in SIA/SIH, relative to 1000 conceptions in the previous 8 city-months according to SINASC. The vertical dashed line indicates 11th November 2015, when Brazilian authorities officially announced the association between the upsurge of Zika and microcephaly in Northeastern Brazil. The dates on the x-axis on Figure A indicate the last day of each week. Panel B plots 14 monthly Difference-in-Difference coefficients since Zika Alert. The dependent variable is the incidence of dengue tests to pregnant women from SINAN in the city-month. This outcome is measured in the date of outcome rather than in the date of conception, as in the previous tables. The vertical dashed line indicates the Zika Alert on 11th November 2015, when the Brazilian government officially announced the association between the upsurge of Zika and microcephaly in Northeastern Brazil. The y-axis represents the number of months before and after this alert. Month -6 (i.e. six months prior to the alert) is used as a baseline. The y-axis plots the coefficients and their associated 90% confidence intervals (standard errors are clustered by state). Observations are weighted by the number of women in the city in 2012.
Figure A3. Diagnosed Cases of Zika

Notes: The Figure plots monthly difference-in-difference coefficients from 21 exclusive dummies since the Zika alert. Month -6 (six months prior to the alert) is considered as the baseline. The dependent variable is the confirmed cases of Zika (ICD code A.928) in the city-month. The x-axis represents the number of months before (negative) and after (positive) the alert. The y-axis plots the difference-in-difference coefficient and the associated 90% confidence interval. Standard errors are clustered by state.