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

Ildo Lautharte Imran Rasul

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Abstract

In 2015, Brazil experienced an epidemic caused by the Zika virus. We use hundreds of millions of administrative records to document household responses to the first public health alert linking the Zika virus to the risk of congenital disease for those *in utero*. We study two margins of behavior: risk avoidance (avoiding pregnancy), and risk mitigation during pregnancy (ultrasounds and abortions). On risk avoidance, we find a 7% reduction in pregnancies post-alert, a response triggered immediately after the alert. On risk mitigation, we find a 9% increase in the use of ultrasounds in the first trimester of pregnancy, and a 5% rise in abortions, concentrated among late term abortions. We document that post-alert all households – irrespective of race or education for example – were able to reduce risks during pregnancy, in line with preventative measures not being costly. In contrast, the avoidance response is driven by more educated mothers perhaps because such households face lower costs of altering their plans around the timing of fertility. We further discuss consequent impacts on birth outcomes, supply side responses, and how our findings extend to household responses to health alerts related to other viral threats. *JEL Classification: I12, J13.*

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1 Introduction

Viruses 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 economic costs of outbreaks are significant: even before COVID-19, the annual global cost of moderately severe to severe pandemics was estimated to be .7% of global income, greater than the costs of natural disasters, and comparable to those from climate change [World Bank 2017]. Viral outbreaks can also severely restrict social interactions and economic exchange, while in the long term they can impact morbidity, human capital accumulation and economic growth [Almond 2006, Fogli and Veldkamp 2021].

We study the Zika epidemic in Brazil in 2015. This event marks the first 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 included microcephaly – a neurological disorder among newborns in which the occipitofrontal (head) circumference is two standard deviations below the mean for age and sex [WHO 2014]. Such birth disorders are likely to have severe lifetime consequences. The primary vector (carrier) for Zika, the *Aedes Aegypti* mosquito, infects two million Brazilians each year, and 300 million globally [WHO 2014]. Work in life sciences suggests over two billion individuals inhabit areas with suitable environmental conditions for *Aedes Aegypti* [Messina *et al.* 2016].

We study household responses to the first widespread official public health alert from the Brazilian government informing households of the link between Zika and risks of congenital disease for those *in utero*. Such alerts are a vital policy tool in early stages of epidemics, when household behavioral responses play a key role in determining the severity of viral outbreaks. Using hundreds of millions of administrative records, we examine a rich set of chronologically sequenced fertility-related responses to the public health alert. Our analysis is divided into three stages. On risk avoidance behavior, we study the extent to which households avoid pregnancy post-alert. On risk mitigation behaviors during pregnancy, we study the use of ultrasounds and abortions. Finally, we study impacts on the composition of those that conceive and give birth post-alert (and so neither avoid nor terminate pregnancy), and the consequent impacts on birth outcomes post-alert related to the incidence of microcephaly and birth weight.

Our analysis replicates and builds on existing evidence using alternative research designs on how pregnancy rates were impacted during the Zika epidemic [Rangel *et al.* 2020], as well as descriptive evidence from small-scale survey and qualitative data on household perceptions of epidemic risks [Diniz *et al.* 2017, Marteleto *et al.* 2017, Quintena-Domeque *et al.* 2018]. Our central contributions are to develop a research design to identify the causal impacts of the alert on behavior and use this to present a combination of new insights on household avoidance *and* mitigation responses, to provide new evidence on the timing of entry of Zika into Brazil, and to highlight how the course of the epidemic could have been different if policy makers were able to harness administrative data in real time. Finally, although our focus is on household behavior, we also present novel evidence on the nature of supply side responses to the epidemic and public health alert among health personnel.

The epidemic timeline 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 known that Zika was present in Brazil but it was thought to be a 'dengue-like' infection, and harmless to newborns. On November 11th the Brazilian government issued an alert stating an upsurge in microcephaly in the North East of the country. On November 17th, scientists confirmed the detection of the Zika virus (ZIKV) in the amniotic fluid of two pregnant women, whose foetuses had microcephaly [PAHO/WHO 2015]. In February 2016 the WHO launched an alert stating microcephaly was an international concern and a pandemic was 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].

Our research design exploits differences in outcomes between pre- and post-alert periods during the epidemic year when ZIKV was known to be in Brazil and pre-epidemic years. Differences in outcomes pre-alert in the epidemic year relative to earlier years identifies the biological impact of ZIKV on outcomes when Zika is known to exist but thought to be dengue-like. Differences in outcomes post-alert relative to earlier years identify the impact of Zika being known to relate to congenital malformations. Our parameter of interest is the difference between these effects, capturing the pure impact of the informational alert linking ZIKV to microcephaly.

We conduct our analysis combining 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 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 measure fertility responses to the health alert. We examine mitigation responses during pregnancy by merging 400 million inpatient and outpatient administrative records. These cover more than 70% of hospitalizations, including all those in public hospitals and a subset of private hospitals. These record the exact date and hospital of admission, ICD-10 codes for primary and secondary reasons for admission, and medical procedures undertaken. We use these to measure post-alert changes in behavior during pregnancy such as the use of ultrasounds and abortions.[1]

Our results are as follows.

First, on risk avoidance the public health alert led to a significant and 7.2% reduction per month in conceptions leading to live births. The magnitude of the effect is of economic significance, equivalent to 18,000 fewer children being conceived each month post-alert, or 53% of the variation in conception rates across months of the year due to seasonality in fertility. 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%.

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. The post-alert impact on conception rates never becomes positive and significant: this suggests not just a delay in pregnancy timing, but a net reduction in the number of births over our study period.

Second, the administrative birth records allow us to measure heterogenous avoidance responses to the alert. The reduction in pregnancies is driven by older and higher educated women. There are multiple reasons why households with higher educated mothers might have responded more: (i) they were better informed of the risks; (ii) they face lower costs of altering their fertility timing (say because they have more bargaining power within marriage); (iii) they perceive higher costs of having a child with microcephaly.

Third, among those conceiving post-alert, there are also mitigating responses during the first trimester of pregnancy such as an increased use of ultrasound (9%). On abortions, despite severe legal restrictions, 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.

Fourth, as a stepping stone to consider birth outcomes, we document a slight change in the composition of those that conceive and go onto give birth post-alert (and so neither avoid nor abort pregnancy): we find small changes towards younger, less educated and lower SES mothers

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[1] Beyond its scale and detail, there are two other advantages of using administrative data over survey data that some of the earlier literature has used to study epidemic responses. Using diagnosis reports of trained professionals reduces recall bias and other measurement errors relative to self-reported survey data. It also mitigates concerns over experimenter demand effects.

post-alert. On birth outcomes, we document a marked rise in microcephaly for children conceived pre-alert (by 1324%) – that relates to the biological effect of Zika. For children conceived post-alert and going to term, there is *no* significant difference in rates of microcephaly relative to children born in similar months in pre-epidemic years. Hence despite post-alert births being concentrated among younger and lower educated mothers, our results are consistent with these mothers taking offsetting precautions to mitigate the risk of mosquito bites and Zika infection during pregnancy.

To examine precautionary behaviors during pregnancy, we calculate relative risk ratios for microcephaly across subgroups (the share of newborns with microcephaly with mothers in group g, divided by the share of all mothers in group g). 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. This pattern reflects pre-alert differences in exposure to mosquitoes and avoidance behaviors against bites. Post-alert the risk ratios across all groups converge towards one. This equalization of microcephaly risks suggests that post-alert, *all* women responded to health information during pregnancy, taking precautionary behaviors to avoid Zika.

The fact that all groups – irrespective of their race, marital status, education and age – are able to reduce the risks of microcephaly during pregnancy is in line with preventative measures not being costly (wearing long and light colored clothing, using mosquito repellent or insecticides). This is in contrast to the earlier results on heterogenous responses to the health alert in terms of risk avoidance, where the delay in conceptions is driven by higher education households. Combining the evidence from avoidance and mitigation behaviors rules out that higher educated mothers responded more in terms of delayed conceptions *because* they were better informed of risks from Zika – that runs counter to the evidence on mitigation behaviors during pregnancy that are found across all subgroups. Rather the evidence suggests more educated households might be able to delay conception because they face lower costs of altering their planned fertility timing, or they perceive higher costs of having a child with microcephaly.

Our findings have two implications for policy during epidemics. First, as responses to public health alerts during evolving epidemics are heterogeneous, and it is important for policy makers to consider those groups for whom risk avoidance is most costly. Alternative interventions could be targeted to such groups, perhaps leveraging behavioral insights to shift behavior [Haushofer and Metcalf 2020]. Second, the administrative data reveal new features of the Zika epidemic. For example, we show that microcephaly cases actually started rising from December 2014. This suggests the virus might have been present in Brazil months before the Federal government was officially notified of a rise in microcephaly cases in the North East, in October 2015. This earlier timing matches with 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 Polynesian countries with a high incidence of Zika at the time [Triunfol 2016]. Hence being able to analyze administrative data in real time can have large benefits at the onset of a viral epidemic.

Finally, although our focus is on household responses, we also briefly discuss additional 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. We consider outcomes related to the organization of hospitals, the provision of counselling on contraceptive use by health personnel, and testing for the virus.

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

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.* [2019], Christensen *et al.* [2021], Maffioli [2021] and Bandiera *et al.* [2025] 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.* 2018] 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]. We build on this descriptive work using a novel research design and tens of millions of administrative records to examine responses to new information on the health consequences of ZIKV.[2,3]

Rangel *et al.* [2020] also use administrative records to estimate causal impacts on fertility of the Zika outbreak in Brazil exploiting geographic variation in exposure. As we detail later, our results largely replicate their findings. They do not however examine outcomes beyond fertility. In contrast, we document a rich set of responses in relation to risk mitigation behaviors during pregnancy, consequent impacts on birth outcomes, and responses of health care providers. Economic epidemiological models of disease diffusion emphasize that being able to track this sequence

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[2] Diniz *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.* [2018] 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.

[3] Outside of epidemics, an older literature has studied household responses to information on new health risks such as BSE [Adda 2007], and the MMR vaccine [Anderberg *et al.* 2011].

of behaviors is critical. The key insight from such models is that endogenous avoidance and mitigation 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, Auld *et al.* 2025]. Such models suggest risk avoidance and mitigation responses are triggered when information on the incidence of a (contagious) disease crosses a threshold [Philipson 2000]. Our results document which households undertake avoidance behaviors, which undertake mitigatory responses, and dynamics along both margins. These are all key inputs into epidemiological models of viral outbreaks.

Section 2 details the Zika epidemic in Brazil. Section 3 describes our data and empirical method. Section 4 presents results on household responses to the epidemic, and briefly discusses supply side responses to the public health alert by health personnel. 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 additional results.

2 Zika

2.1 Background

The Zika virus (ZIKV) is a flavivirus carried by the *Aedes Aegypti* mosquito, that is familiar to Brazilians as the primary vector for malaria, yellow fever and dengue. 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]. The most prominent congenital disease recognized during the epidemic was microcephaly.[4]

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

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[4] 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, 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].

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: 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.

2.2 Timeline

In March 2015 the WHO received notification from Brazil regarding an illness transmitted by the *Aedes Aegypti* mosquito, but not detected by standard tests. On October 16th the WHO issued a communique confirming the autochthonous transmission of ZIKV in North East of Brazil. The communique emphasized monitoring whether ZIKV had spread to other areas, and for signs of any neurological and autoimmune complications. There was no mention of risks to children *in utero*. Hence until early November, the common perception among the public and health care personnel was that Zika was a ‘dengue-like’ infection, harmless to newborns. The period from May to October 2015 marks the pre-alert period for our analysis.

On November 11th the Brazilian government issued a widespread 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 officially made. It was recommended pregnant women take precautions to avoid mosquito bites, and to use contraceptive methods to postpone or delay pregnancies [Borges and Countinho 2021]. Health authorities further recommended increasing access to contraceptives, and to strengthen counseling to inform women who wanted to get pregnant about cases of microcephaly. The *Jornal Nacional* TV news network, reaching 110 million individuals daily, broadcast the alert nationwide the same day. November 2015 marks the start of the post-alert period for our analysis.[5]

3 Data, Descriptives and Empirical Method

3.1 Administrative Records

We exploit administrative records providing near universal coverage of birth and hospital care statistics from all 27 states and 5565 cities (municipalities) in Brazil from January 2013. Our

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[5] 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.

analysis of pregnancy and birth outcomes is based on 12 million birth records (*SINASC*), covering all live births in hospitals (public and private), and in homes, from January 2013 to December 2017. *SINASC* records the date and location of birth (city and hospital), city of residence and 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. We use this to construct an estimated date of conception. Birth outcomes recorded include delivery method and birth weight. Finally, *SINASC* contains ICD-10 codes for congenital malformations among newborns, including microcephaly.[6]

Our working sample is based on $11,769,217$ birth records covering women aged 12 to 49 with no missing data on estimated conception dates. These run from January 2013 to December 2017, so covering conception dates from March 2012 to February 2017. As *SINASC* does not contain individual identifiers, we cannot link individuals across pregnancies. We aggregate the data to the city-month level (cm), where we have $267,120 = (5565 \text{ cities} \times 48 \text{ months})$ city-month observations. We define a city-month conception rate$_{cm} = 1000 \times (\frac{\text{Number of pregnancies}_{cm}}{\text{Number of women}_{c,2012}})$. 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.

To measure behavior during pregnancy, we merge 400 million inpatient and outpatient administrative records (*SIH* and *SIA*). These cover all public hospitals and a subset of private hospitals that work with the National Health Service, covering more than 70% of all hospitalizations. These record the date and hospital of admission, and city of residence of the mother. ICD-10 codes are recorded for primary and secondary reasons for admission, separate codes are provided for each primary and secondary medical procedure undertaken. These data allow us to measure risks of Zika infection and behaviors of health service personnel, such as the use of dengue tests and counseling on contraceptive use. Our working sample is constructed from inpatient-outpatient records from January 2013 to June 2017. We again aggregate to the city-month level (cm), where we have $300,510 = (5565 \text{ cities} \times 54 \text{ months})$ city-month observations.

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[6] On demographic characteristics of mothers, race categories are white and non-white. Education categories are basic, high school and diploma or more. Marital status is single or married. ICD-10 codes follow the International Statistical Classification of Diseases and Related Health Problems 10th Revision, 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 30.5cm for boys and 30.2cm for girls. Given our results on microcephaly are based on unchanged ICD-10 codes, none of our results are impacted by these definitional changes, further details of which can be found (in Portuguese) at http://portalms.saude.gov.br/images/pdf/2015/dezembro/09/Microcefalia—Protocolo-de-vigil–ncia-e-resposta—vers–o-1—-09dez2015-8h.pdf

3.2 Descriptives

3.2.1 Microcephaly

The clearest marker of the severity of the Zika epidemic is the incidence of microcephaly. Figure 1A shows the time series of microcephaly among newborns, by region, as derived from birth records. For pre-epidemic cohorts, 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 North East was the mostly affected region: at the peak, it had almost 10 times the number of microcephaly cases as the next most affected region. The incidence of microcephaly peaks around December 2015 and diminishes steadily thereafter, but 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 2522 cases. Figure 1B shows the spatial variation in microcephaly, highlighting the variation in incidence within regions.[7]

As Figure A1 shows, these temporal and spatial patterns are very different to those for dengue, that is a long-standing (urban) disease also carried by the *Aedes Aegypti* mosquito.[8]

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 longer to disseminate. We present evidence using online archives of three leading national newspapers: *Folha de Sao Paulo*, *Estadao* and *O Globo* (these archives cover both online and national editions, and we exclude regional printed editions). In each archive, we searched for 'microcephaly'. Figure 2A shows the 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 persisting until mid-2016.[9]

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[7] 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 *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 *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 *et al.* 2019].

[8] 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 (Panel B of Figure A1), while Zika was concentrated in the North East.

[9] Ribiero *et al.* [2018] present qualitative evidence on the media coverage of Zika in *O Globo* and *Folha de São Paulo*. They analyze 186 articles published between December 2015 and May 2016, and argue this reveals a

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 some public awareness of Zika and microcephaly pre-alert, a spike in awareness post-alert, with the spatial pattern of searches being more widespread (as shown in Panel C), and not overly concentrated either in the North East (where the majority of microcephaly cases occurred) or in the South East (where dengue was most prevalent).[10]

3.2.3 Doctor Awareness

We assess doctors' awareness of Zika using administrative records from the national system of notifiable diseases (*SINAN*). This details 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, covering 3.2 million patients, but the series discontinues thereafter. In any case, the Ministry of Health made Zika-related notifications compulsory from February 2016. Panel A in Figure 3 shows the time series of microcephaly recorded in doctors' notes (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 misdiagnosed [Petersen *et al.* 2016]. There is however a clear spike 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, so again there is awareness among doctors pre-alert, but such observations increase rapidly after the alert. Had such administrative data been available in real time, the link between Zika and congenital diseases might have been noted earlier. Finally, Panel C shows that among patients reporting dengue-like symptoms, there was a rapid increase in the mention of pregnant women post-alert (these mentions occur at four to five times the rate compared to a year earlier). This increase occurs *after* the formal alert was issued in November 2015.

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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. 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.

[10] 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.* [2018] 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.

3.3 Research 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 with little consequence for those *in utero*; (ii) following the alert on November 11th 2015, the post-alert period covers November 2015 to April 2016, when information on the association between ZIKV and congenital disease was widely disseminated. For each period we consider as counterfactuals the corresponding period from the two earlier pre-epidemic years. We estimate the following specification for outcome y in city-of-residence c in month m in period t:

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

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. $PRE\text{-}ALERT_m$ is a dummy equal to one from May to October for years 2013 to 2015, and $POST\text{-}ALERT_m$ is a dummy equal to one from November to April for years 2013/14 to 2015/16.

α_m are month fixed effects capturing seasonal variation in pregnancies. α_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. ε_{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 share of women aged 12-49 in city c.[11]

β_1 captures the difference in conception rates from May to October 2015 and the exact same months in earlier years. Following Rangel *et al.* [2020], we label this a pre-alert or '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 – as the evidence on public awareness in Figure 2 suggests could have been the case. β_2 captures the difference in conception rates from November 2015 to April 2016 and the exact same months in earlier years: this estimates the impact of Zika being present but also known to relate to congenital malformations such as microcephaly.

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[11] Temperature controls are derived from data from the National Instituter 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. Weights are the inverse of the distance between the city and the station.

Our parameter of interest is the difference between these estimates, $\beta_2 - \beta_1$, because this captures the pure impact of the public health alert linking ZIKV to microcephaly. The identifying assumptions are that: (i) conception rates in the post alert period of the Zika epidemic period would have followed pre-existing trends in the counterfactual of no alert being issued; (ii) any responses arising from pre-alert knowledge on the existence of Zika but when it is thought to be dengue-like, are the same in pre- and post-alert periods during the epidemic.

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 and the ability to complete desired levels of total fertility. Panel A of Table 1 presents evidence on conception rates, by time period: (i) in pre-epidemic (control) years, conception rates are higher between May and October than between November and April (4.24 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 vs 4.19); (iii) conception rates fall further during the epidemic post-alert than similar months in earlier years (3.57 vs 3.91); (iv) the pre-post difference in conception rates in the epidemic year relative to earlier years is negative and significant ($-.296$, $p = .000$), corresponding to an unconditional 8% fall in conception rates relative to November-April months pre-epidemic.

4 Results

4.1 Preventive Responses: Conception Rates

Table 2 shows regression estimates of how conception rates respond to the public health alert. The foot of each Column reports the key difference $(\widehat{\beta}_2 - \widehat{\beta}_1)$, isolating the impact of the alert on the outcome of interest, with its associated 95% confidence interval. To benchmark magnitudes, we show the baseline mean of the outcome variable (the pre-alert May to October period in pre-epidemic years), and the percentage impact the estimate of interest corresponds to.

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 in which we find that: (i) $\widehat{\beta}_1$ is not statistically different from zero, so that pre-alert, any awareness of the presence of Zika in itself does not change conception rates relative to earlier years; (ii) $\widehat{\beta}_2 = -.319$ ($p = .000$); (iii) the parameter of interest is $\widehat{\beta}_2 - \widehat{\beta}_1 = -.306$ ($p = .000$). The magnitude of this effect corresponds to a 7.21% reduction in conception rates caused by the public health alert, that is precisely estimated: from the 95% confidence interval, we can rule out a reduction smaller than $-.241$ (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 (α_m) is $\alpha_{August} - \alpha_{February} = .582$. Hence the response to the alert represents 53% of the natural monthly fluctuation in conception rates.

The remaining Columns in Table 2 probe the common trends assumption underlying the research design. Overall we find the core estimate of the impact of the alert on conception rates to be robust in magnitude and significance. For example, the specification in Column 5 allows for state-specific linear time trends in conception rates ($t.\alpha_s$): the resulting 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 estimates remain unchanged allowing for city-specific time trends ($t.\alpha_c$). Taken together, these checks help rule out the concern that gradually changing political or macroeconomic conditions impacted fertility during the epidemic year [Castro *et al.* 2018].[12]

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.[13]

Table A1 presents a battery of further checks on our main results related to: (i) the specification of the estimating equation; (ii) changes to the sample of cities used; (iii) extending the control period by adding birth records from another pre-pandemic birth cohort from 2012; (iv) endogenous health policy responses; (v) endogenous household migration responses to the epidemic.

A final check relates to the concern that the fall in conception rates could be driven by individuals avoiding hospitals post-alert. The literature on epidemics with high degree of human-to-human contagion (such as SARS, H1N1 or Ebola) has documented that the fear of contagion can cause

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[12] In these specifications we find evidence that $\widehat{\beta}_1 < 0$. This reduction in pre-alert conception rates relative to the same period in earlier years reflects the kinds of awareness and anticipatory effects consistent with the descriptive evidence in Figure 2.

[13] The magnitude of the response in the North East is very similar to that implied by survey evidence collected from women surveyed in that region during the outbreak. For example, among the $11,000$ women aged 15-49 surveyed between March and June 2016, Quintena-Domeque *et al.* [2018] 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 design implies a 10% reduction in conception rates in that region. In other comparisons to the literature, we note that Castro *et al.* [2018] use data from 2010-16 to forecast the change in births in Brazil due to Zika using an ARIMA model – estimating a 4.2% reduction. Marteleto *et al.* [2022] also use ARIMA models to forecast fertility drops in Brazil due to the epidemic: they find inconclusive evidence of impacts. Finally, Rangel *et al.* [2020] use the same administrative birth records from Brazil as we do to document fertility impacts of the epidemic, separating biological and behavioral responses. They use two designs: a synthetic control approach and a difference-in-difference approach exploiting spatial differences in exposure. They document a near 20% reduction in fertility relative to a counterfactual absent the epidemic.

individuals to avoid health care services [Bennett *et al.* 2015, Evans *et al.* 2015, Christensen *et al.* 2021], potentially worsening consequences of epidemics. However, such avoidance behaviors are less likely for Zika because the dominant transmission channel is via mosquitoes, not contagion from others. Nevertheless, to check for this we use the linked inpatient-outpatient records to estimate how hospital admissions change over the epidemic. These results in Table A2, confirm households do not avoid using hospitals during the Zika epidemic.[14]

4.1.1 Dynamics of Preventive Responses

Even though national media widely broadcast the link between Zika and microcephaly, preventive responses to the health alert might not be immediate if it takes time for information to spread, or for individuals to become persuaded of the risks from Zika infection. We use two approaches to understand these dynamics. First, the birth records provide an estimated *week* of conception. To examine short run dynamic responses to the alert we compare weekly conception rates in the period around the alert to the same week in the year before. This evidence is in Panel A of Figure 4, and although the 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; (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.

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

$$y_{cmt} = \alpha_m + \alpha_c + \sum\nolimits_t \beta_{3t} Alert\_time_t + \gamma X_{ct} + \varepsilon_{cmt}, \tag{2}$$

where $Alert\_time_t$ is the number of months since the health alert linking Zika and microcephaly. $Alert\_time_t$ is defined to be zero in November 2015 and we allow it to run from -6 to $+15$. We define conception rates in logs so that we can more easily compare percentage impacts across time. Panel B of Figure 4 shows the sequence of $\widehat{\beta}_{3t}$*'s* from (2). There is little evidence of a strong downward trend pre-alert (relative to the baseline period of six months pre-alert), but there are significant falls in conception rates for 9 months post-alert (and only one month in which they rise post-alert). Conception rates fall the month before the official alert: this effect is entirely driven

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[14] 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. 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. Christensen *et al.* [2021] 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.

by households in the South East, where dengue is most prevalent and households have the best access to contraception and medical treatment. Focusing on dynamic responses in the North East, the sequence of $\widehat{\beta}_{3t}$'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.[15]

The post-alert impacts never become positive and significant: this suggests not just a delay in pregnancy timing, but also a net reduction in the number of births over this period. However, we cannot draw conclusions about lifetime impacts on total fertility. We return to this issue below when we examine heterogeneous responses, including for older women for whom any reduction in conception rates is more likely to translate to lower lifetime fertility.

4.1.2 Heterogeneous Responses

The administrative records allow us to precisely measure preventive responses to the alert across subgroups. To do so, for each subgroup, we estimate a specification analogous to (1), but define conception rates in logs to directly compare percentage impacts across subgroups. Panel A of Figure 5 plots the parameter of interest $\widehat{\beta}_2 - \widehat{\beta}_1$ for each subgroup, and its associated 90% confidence interval. We find that: (i) there are few significant differences in responses based on race (white versus non-white) or marital status (single versus married); (ii) there is a strong gradient of responses with education: low education households (in which the mother has up to 7 years of schooling) respond less than households with high-school education (8 to 11 years), who in turn respond less than households in which the mother has a diploma (12 or more years).

On impacts by age, Panel B shows there is a U-shaped gradient between conception rate responses and age: mothers in their 30s respond most to the alert. 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%. Combining information on age and education the right hand side of Panel B shows that in each age cohort, higher education mothers have larger reductions in conception rates. These results also largely replicate the findings in Rangel *et al.* [2020], who also document larger responses among more educated, older and wealthier mothers.[16]

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[15] These dynamic responses are shorter-lived than suggested by qualitative evidence collected from mothers during the epidemic. As reported in Marteleto *et al.* [2017], when discussing how long women intended to postpone pregnancy because of ZIKV, responses varied from specific periods, like two or three 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."

[16] Exploiting regional variation in exposure, Rangel *et al.* [2020] show that fertility impacts of the epidemic are substantially larger among higher SES households (a 25% reduction) relative to lower SES households (a 15% reduction). Survey evidence reported in Quintena-Domeque *et al.* [2017] also finds that more educated mothers

There are multiple reasons why households with higher educated mothers might have had greater preventive responses following the alert: (i) they were better informed of the risks; (ii) they face lower costs of altering their fertility timing (say because they have more bargaining power within marriage); (iii) they perceive higher costs of having a child with microcephaly. We will be able to say more to rule out explanation (i) after considering behavioral responses during pregnancy across subgroups.

4.2 Mitigatory Responses During Pregnancy

We next examine behavioral responses to the public health alert to mitigate risk *during pregnancy* using linked inpatient-outpatient administrative records (*SIH* and *SIA* from *DATASUS*). We construct a city-month panel and estimate specifications analogous to (1) where the outcomes are pregnancy tests, ultrasounds and abortions. All rates are calculated as the number of outcomes in city c in time period t per 1000 women that conceived in city c in the previous three months, as only women in the first trimester of pregnancy are 'at risk' of each outcome.[17]

Panel B of Table 1 presents descriptive evidence on these outcomes. Pregnancy test rates rise over time, reinforcing the idea that households were not avoiding hospitals during the epidemic. On ultrasounds, we see that pre-alert around a quarter of women undergo an ultrasound, and this rises significantly post-alert: the pre-post difference in conception rates in the epidemic year relative to earlier years is 22 ($p = .000$), corresponding to a 9% rise. Finally, on abortions, despite legal restrictions, abortion rates are high pre-epidemic: 16% of women pregnant in the pre-alert period have an abortion, and this rises post-alert: the unconditional difference is 7.8 ($p = .004$), corresponding to a 5% rise.[18]

Table 3 presents the regression results for these outcomes, making two further refinements. First, we consider two samples: all cities, and the subset of cities reporting a strictly positive outcome in at least one time period. This is relevant because not all cities provide pregnancy tests or ultrasounds in hospital, although the set of hospitals providing such services does not change

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are more likely to report being aware of the association between Zika and microcephaly.

[17] 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] quantify the number of illegal abortions using the Brazilian National Abortion Survey of 2016, estimating 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 $213,000/1,445,425 = .147$.

[18] 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.

over the epidemic. Second, we split pre- and post-alert periods into quarters. This allows us to more precisely pin down changes in behavior among those that conceived in each period. The inpatient-outpatient records contain no details on conception date, with outcomes being 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 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 that best isolates the pure impact of the alert on those that conceived pre- and post-alert compares between these quarters and the corresponding pre-epidemic years. This estimate is shown at the foot of each Column in Table 3.

The estimated effect of the alert for pregnancy tests is not different from zero. In contrast, the impact of the alert on ultrasound rates is positive and significant in both city samples. The magnitudes of effects are 39 and 45 respectively, that both correspond to 16% increases over the baseline rate. The impact of the alert on abortion rates is positive and significant in both samples. The magnitudes of effects are 16 and 19 respectively, that both correspond to 9% increases over the baseline – a large effect despite controversy over the use of abortions during the epidemic. The response corresponds to just under $4,000$ more abortions per month post-alert, or 20% of the overall decline in monthly conceptions leading to a live birth documented earlier.[19]

An alternative measure of abortions by city-month can be constructed using administrative records from the Mortality Information System (*SIM*). These cover all cities but relate to late-term abortions: 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. Column 4 of Table 3 shows that for late-term abortions, the estimated impact of the alert is positive ($p = .000$), corresponding to a 15% increase. Overall, our findings suggest that there are both more abortions post-alert, and a shift in the timing of abortions later in pregnancies – also consistent with the results reported in Castro *et al.* [2018]. For ultrasounds and both measures of abortion, the key estimate is significantly different from zero and is driven by changes in behavior during pregnancy of those that conceived post-alert ($\widehat{\beta}_2 > 0$) rather than changes in behavior among those that conceived pre-alert ($\widehat{\beta}_1 = 0$).

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[19] As reported by *O Globo* on 5th February 2016, "*...the National Conference of Brazilian Bishops (CNBB) declared that the occurrence of microcephaly does not justify abortion*" [Ribiero *et al.* 2018]. On the other hand, in September 2016 the National Prosecutor publicly expressed his support for abortion among pregnant women infected with ZIKV, although no legislative change has been enacted [Castro *et al.* 2018].

4.3 Birth Outcomes

Before considering birth outcomes, we first examine how characteristics of those who conceive *and* whose pregnancies go to term are impacted by the public health alert. We do so by estimating specification (1) but where the outcome is the percentage of pregnancies to teen mothers in the city-month, to non-white mothers, the percentage with missing data on fathers' age (as a proxy for out-of-wedlock pregnancies), to mothers with basic education, and the average age of mothers.

The results in Table A3 show slight changes in the composition of mothers from pre- to post-alert in the epidemic year. There is a greater share of teen mothers, mothers with basic education and an overall reduction in mothers' average age. However, the magnitude of these changes are all minor, ranging from .6% to 3% of the baseline mean, with each change being precisely estimated. To the extent these changes impact birth outcomes post-alert, we might expect the direction to be to worsen outcomes, holding constant all other factors including behavior during pregnancy.

4.3.1 Microcephaly

The first birth outcome we examine is the main Zika-specific risk: microcephaly. Panel C of Table 1 shows the incidence of microcephaly pre-alert is only .06 per 1000 births (or 1 in $17,000$ births) among those conceived from May to October; (ii) post-alert, the incidence of microcephaly among those conceived pre-alert rises by factor of 13, while for those conceived post-alert falls by 36%. The unconditional difference is -1.00 ($p = .019$).

Column 1 in Table 4 shows the regression estimate from (1) (so not controlling for mother characteristics). We see a marked rise in microcephaly in children conceived pre-alert: the biological effect $\widehat{\beta}_1$ 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 to the biological effect of ZIKV when Zika is known to exist but thought to be dengue-like. For children conceived post-alert, there is *no* significant difference in rates of microcephaly relative to children born in similar months in pre-epidemic years: $\widehat{\beta}_2 = -.239$ and is not statistically different from zero. The parameter of interest, $\widehat{\beta}_2 - \widehat{\beta}_1$, is -1.04, corresponding to a 1700% reduction in microcephaly rates among those conceived post-alert relative to those conceived pre-alert.[20]

These changes in birth outcome derive from two sources: (i) changes in the composition of those that conceive post-alert and go on to complete pregnancy; (ii) changes in behavior during pregnancy. We can use our data to assess both sources.

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[20] 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.

On (i), we follow the approach of Currie and Schwandt [2014] and additionally control for mother characteristics and interactions of each with $(POST-ALERT_m \times Zika_t)$. Specifically, we control for maternal characteristics (aggregated to the city-conception month level. These include an indicator for teenage mothers (≤ 18), non-white mothers, mothers with basic education (≤ 3 years of schooling), an indicator for missing father's age and average maternal age (in years). The results in Column 2 show that the pre-alert incidence of microcephaly rises by .790 per 1000 births, near identical to the estimate in Column 1. The post-alert effect $\widehat{\beta}_2$ remains not different from zero. The impact of the health alert is not statistically different from zero but is imprecisely estimated. The point estimate still reflects a 526% increase in the incidence of microcephaly, but that is one third the magnitude (and of opposite sign) to that estimated in Column 1 when mother characteristics are not controlled for. Hence despite post-alert births being slightly more likely to be concentrated among younger and lower educated mothers, the findings are consistent with these mothers taking offsetting precautions to mitigate the risk of Zika infection during pregnancy.[21]

On (ii), to examine evidence of precautionary behaviors during pregnancy, we calculate relative risk ratios for microcephaly for subgroups (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, and do so separately for the pre- and post-alert periods. Figure 6 shows the results. Pre-alert, risk ratios differ markedly from one across subgroups. For example, 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. Post-alert, risk ratios across all groups converge towards one. This equalization of microcephaly risks again suggests that post-alert, *all* women took precautionary behaviors to avoid Zika during pregnancy.

The fact that all groups – irrespective of their race, marital status, education and age – are able to reduce the risk of microcephaly during pregnancy is in line with preventative measures not being costly (wearing long/light colored clothing, using mosquito repellent/insecticides). This contrasts to heterogenous preventive responses to the alert, where the delay in conceptions was driven by higher education households. Combining the evidence from preventive and mitigating behavior helps rule out that the greater response in delayed conception of higher educated mothers was *because* they were better informed of Zika risks – that runs counter to the evidence on preventive behaviors during pregnancy that are found across all subgroups. Rather the combined evidence

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[21] This conclusion does not change if we split the sample between cities that do/do not offer abortion or ultrasound services. The impacts on microcephaly are similar across cities: this suggests ultrasound technology is unlikely to detect microcephaly during the first trimester of pregnancy, when abortion remains possible.

suggests more educated households might delay conception because they face lower costs of altering planned fertility timing, or they perceive higher costs of having a child with microcephaly.

4.3.2 Dynamics of Microcephaly

We provide further insights on the epidemic by considering the dynamics of microcephaly. To do so we estimate a specification analogous to (2), where the outcome is whether a newborn conceived in time period t, is born with microcephaly. Figure 7A shows the estimates, stretching back to more than one year pre-alert, and running through to newborns conceived up to 7 months post-alert. Figure 7B shows the results by region: the pre-alert impacts are nearly all driven by increases in microcephaly cases in the North East, with there also being significant (but smaller) increases in microcephaly in the South East. This establishes two new features of the epidemic and the impact of public health alerts.

First, while the peak risk of microcephaly occurs for those conceived 8 months pre-alert (and so almost entirely *in utero* before the public health alert), microcephaly cases actually start rising from December 2014. It however took until October 2015 before the Federal government was alerted about the rise in microcephaly cases in the North East. These estimates suggest the virus might have been present in Brazil months before officially noted. 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]. These results again suggest that had it been possible to analyze administrative birth records in real time, authorities might have become aware of the spike in microcephaly a month before it was actually realized – even such small changes in timing of awareness in the public health system can be critical in the early stages of an epidemic.

Second, Figure 7 shows the incidence of microcephaly falls among those who are *in utero* for any period of time after the public health alert. Hence preventive actions taken at all stages of pregnancy help reduce the likelihood of microcephaly. This is in line with the idea that ZIKV infection at *any point* during pregnancy can impact fetal development [Cauchemez *et al.* 2016]. However it remains the case that point estimates on rates of microcephaly never fall to the levels among those conceived after the public health alert.

4.3.3 Birth Weight

Birth weight is a widely used indicator of neonatal health and correlates with later life health, cognition, educational attainment, wages and longevity [Almond and Currie 2011]. We thus consider how this outcome is impacted by the public health alert. Column 3 of Table 4 shows that among those conceived pre-alert, the biological effect of the likelihood of low birth weight significantly increases relative to pre-epidemic years ($\widehat{\beta}_1 = 1.75$, 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 likelihood of low birth weight also rises relative to pre-epidemic years but not by as much ($\widehat{\beta}_2 = .813$, or 1% of the baseline mean). Hence the overall effect of the public health alert is to cause a significant fall in the incidence of low birth weight (by 1.26%). Additionally controlling for mother characteristics and interactions of each with $(POST - ALERT_m \times Zika_t)$, the biological effect is unchanged as expected, and the impact of the alert is no longer different from zero (although imprecisely estimated).[22]

4.4 Supply Side Responses

Our focus has been on household responses to the public health alert during the Zika epidemic. In the Appendix we present additional novel evidence using administrative records on supply side responses. To summarize those findings, we find little evidence of such responses to the alert in terms of the number of obstetric or neonatal centers, and we find no changes in hospital functioning as measured by the number of committees tasked to control infections or to issue notifications on diseases. The other dimension of supply side responses we explore relate to patient care. 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. We also find no change in induced births, or the use of neonatal triage. We do however document the widespread increase in dengue tests. Absent an 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]. 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%). The time taken to administer such tests might crowd out other forms of patient care – this might also be the case through the increased use of ultrasounds and abortions documented earlier. However, it is difficult to identify where such reallocation towards maternal and child care might have come from if doctors work across sectors, or hospitals can reallocate resources across specializations.[23]

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[22] 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.

[23] In November 2015, $220,000$ soldiers were sent to 300 cities in the North East to provide mosquito nests and advise households on the risk of stagnant water close to homes. $71,000$ soldiers were sent to Rio because of the

5 External Validity

Viral outbreaks increase the uncertainty households face, as they emerge without warning and available treatment. 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 outbreaks. In terms of future viral outbreaks where pregnant mothers are at risk, it is useful to consider whether Brazil differs from other settings 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 its neighbors, and this is mirrored in attitudes towards abortion. Data from the 2014 World Values Survey (WVS) shows 66% of Brazilian men and 74% of Brazilian women believe abortion is never justified. This is higher than in other countries in the region. 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 larger behavioral responses along these margins in less conservative societies.[24]

All viral outbreaks differ from each other in the extent to which: (i) some individuals are more at risk; (ii) their primary vector of transmission; (iii) their degree of contagion, or basic reproduction number (R0); (iv) case fatality rates. At the same time, nearly all new viral epidemics occur without there being a known treatment. Hence, individuals are exposed to increased uncertainty as the length and severity of outbreaks is unknown [Rasul 2020, Auld *et al.* 2025]. In any epidemic or pandemic, countries have the opportunity to quickly learn from neighbors and international scientific cooperation is key. Our analysis shows that a large share of households at risk during the Zika epidemic in Brazil responded to new information, despite the risk of microcephaly being relatively low. We might expect larger behavioral responses to health alerts for viruses with higher case rates. Our findings show responses to health alerts during epidemics can be heterogeneous across groups, so it is important for policy makers to consider those for whom behavioral change

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Olympic Games there in 2016.

[24] Gamboa and Lesmes [2019] estimate that Zika in Colombia led to a 10% reduction in birth rates, using a difference-in-difference design exploiting differences in regions exposed to Zika and others less exposed due to their altitude. Tan and Pang [2022] estimate fertility declines due to Zika in Singapore, comparing more and less exposed urban neighborhoods: their analysis is based on sample of 660 women (and hence $15,840$ person-month observations as they construct a two year panel of birth histories). They find that although fertility declined in exposed and less exposed neighborhoods, there are not significant differences in falls between these neighborhood types. In line with our findings, they also documented fertility responses among low SES households are more dependent on whether they reside in a high or low exposure neighborhood, while this is not the case for high SES households.

is most costly. Alternative interventions could be targeted to such groups, perhaps leveraging behavioral insights to shift behavior [Haushofer and Metcalf 2020].

6 Conclusions

The frequency and diversity of viral outbreaks is increasing over time [Smith *et al.* 2014]. With a lack of preparedness to deal with such viral epidemics, 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 as new viral threats emerge. 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. Understanding endogenous household responses to public health information lies at the heart of this paper, and our analysis has two wider implications for the literature.

First, there are significant changes in cohort size given 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. The medical literature suggests that as infants with congenital Zika infection get older, epilepsy, vision loss, and developmental delays are increasingly recognized [Rice *et al.* 2018]. Hence, as Currie *et al.* [2016] emphasize, the health consequences of epidemics persist long after a country is declared disease-free. In the poorest countries, health systems can be further weakened, persistently worsening responses to future infectious disease outbreaks. Other evidence from epidemics suggests there might be long run gains if exogenous health shocks facilitate the permanent adoption of health-improving behaviors [Aguero and Beleche 2017]. Much remains to be understood on such persistent implications of epidemics.

Second, on research methods, we have used administrative data to study behavioral responses during the epidemic. 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.* 2021], or to shed light on the channels through which aggregate heath shocks impact individuals [Bandiera *et al.* 2025].

As the frequency 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. The recent COVID-19 pandemic leaves little doubt about the social benefit of taking on this challenge.

A Appendix

A.1 Data Appendix

We 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 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 an additional 20%. State health secretaries are responsible for 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 for 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. Information on last menstruation and a doctor's assessment 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 records are incomplete. Focusing on women aged 12 to 49, we drop 2.63% of records with missing data on last menstruation date (required to construct the estimated conception date). We have data for births in 2012, but we only use these for a robustness check because 4.81% of records have missing data on last menstruation date.

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 and 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 date of admission. However, it does not provide patient characteristics. Primary and secondary reasons for admission are coded using International Disease Codes (ICD-10). Unique codes are provided for each primary and secondary medical procedure undertaken. Reason for hospital discharge are 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* record patient characteristics including 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 ICD-10 codes. Unique codes are provided for each primary and secondary medical procedure undertaken. The complexity of procedures is recorded.

The *SIH-SIA* data covers inpatient and outpatient records from January 2013 until June 2017, covering 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 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 from 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 a 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 three million patient samples. The data from 2016 does not provide doctors' notes, so is not useful for our analysis.

Other Data *DATASUS* 2012 provides information on the number of women in each municipality in 2012 – the denominator for our conception rate estimates. The Ministry of Health and the Brazilian Institute of Geography and Economy use information on gender and age categories from the 2010 Census to project city population numbers for 1st July 2012.

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 three leading national newspapers: *Folha de Sao Paulo*, *Estadao* and *O Globo*. These cover online and national editions of each newspaper, and we exclude regional printed editions. 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.[25]

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[25] 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/. The source of World Bank data on contraceptive prevalence is https://data.worldbank.org/indicator/SP.DYN.CONU.ZS?end=2015&locations=BR-UY-AR-PE-

A.2 Robustness Checks

Table A1 presents a battery of further checks on our main results on conception. 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 $POST\text{-}ALERT_m$ 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 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).[26]

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 give birth. We check for this in Column 8 of Table A1 where the outcome is the share of women giving birth in the city-period whose city of residence and city of birth differ. $(\widehat{\beta}_2 - \widehat{\beta}_1)$ is a precisely estimated zero, suggesting the alert did not cause migration across cities, in line with Rangel *et al.* [2020]. We probe this further by focusing on cities where abortions or ultrasound are offered by hospitals: 31% of cities provide abortions and ultrasound, 45% provide neither, 15% provide only abortions, and 9% offer only ultrasound. The cities with the technology and infrastructure to offer these services are the largest ones: 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.[27]

EC&start=1969&view=chart, and for access to prenatal care it is https://data.worldbank.org/indicator/SH.STA.ANVC.ZS?locations=BR-UY-AR-PE-EC.

[26] 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, $t-1, ...t-8$), and the number of women giving birth during months t, $t-1, ...t-8$.

[27] 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

A.3 Hospital Admissions

In Appendix Table A2 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 impact of the public health alert on admission rates among the general population (Column 1), even allowing for state specific time trends (Column 2). Narrowing in on the impact of the public health alert on hospital admission rates for pregnant women, the fall in admission rates is 9%, closely matching the estimated fall in conception rates (Column 3) and this remains so when we allow for state specific time trends (Column 4). These results further help confirm households do not avoid using hospitals during the epidemic.

A.4 Supply Side Responses to the Epidemic

We 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 dengue cases; (ii) inpatient-outpatient records that detail procedures implemented on patients (as recorded by physicians). The results are in Table A4 where all outcomes are measured in period t for each city-month.

A.4.1 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 of Table A4 shows: (i) no change in the use of dengue tests among pregnant women during the pre-alert period ($\widehat{\beta}_1 = 0$) (ii) a rise in the use of dengue tests for pregnant women post-alert ($\widehat{\beta}_2 > 0$): the estimated parameter of interest 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 alert. Although the series is noisy, there is a clear structural break in the use of dengue tests in the week after the alert, with a rising trend thereafter. Figure A2B plots the dynamic estimates from a

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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).

specification analogous to (2) for dengue test rates for pregnant women by month. 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 dengue tests, Columns 2 and 3 in Table A4 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.[28]

A.4.2 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 A4 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 estimated parameter of interest corresponds to a 1466% increase in Zika infection rates. Beyond diagnosed cases, there might also be undiagnosed cases of Zika. We define these as where a doctor has performed tests for dengue, yellow fever and chikungunya (all transmitted by *Aedes Aegypti*), but did not diagnose any of these. We see rises in potentially undiagnosed cases of Zika over the epidemic, with the parameter of interest increasing by 22%. 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 estimates. Pre-alert, there are almost no changes in the incidence of Zika diagnosis

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[28] Table A5 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.

relative to pre-epidemic years. There is a clear rise in Zika diagnosis post-alert: this peaks four months after the alert, and remains significantly higher up to seven months post-alert. The gap in timing between the actual incidence of Zika and when it was being diagnosed by health personnel is seen by comparing Figures 7 and A3. The peaks are 12 months apart, suggesting a year lag in the peak of ZIKV infection and Zika diagnoses by health personnel.

A.4.3 Counseling on Contraceptive Use

Column 6 of Table A4 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 contraceptive availability. 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].[29]

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 estimated difference is a precisely estimated zero (Column 7).

A.4.4 Hospital Functioning

We examine hospital functioning over the crisis using the National Register of Health Establishments (*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 committees. 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.[30]

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[29] The inpatient-outpatient administrative records detail other 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. Hence we do not give much prominence to them. Finally, we note there is no change in induced births (in line with the earlier result of no change in births by Caesarean section), or the use of neonatal triage (the process of short-term evaluation and management of infants after delivery).

[30] On the number of obstetric centers and the number of neonatal centers we find the impact of the health alert on 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

References

[1] ADDA.J (2007) "Behavior Towards Health Risks: An Empirical Study Using the 'Mad Cow' Crisis as an Experiment," *Journal of Risk and Uncertainty* 35: 285-305.

[2] ADDA.J (2016) "Economic Activity and the Spread of Viral Diseases: Evidence from High Frequency Data," *Quarterly Journal of Economics* 131: 891-941.

[3] AGÜERO.J.M AND T.BELECHE (2017) "Health Shocks and Their Long-lasting Impact on Health Behaviors: Evidence from the 2009 H1N1 Pandemic in Mexico," *Journal of Health Economics* 54: 40-55.

[4] AHITUV.A, V.HOTZ AND T.PHILIPSON (1996) "Is AIDS Self-limiting? Evidence on the Prevalence Elasticity of the Demand for Condoms," *Journal of Human Resources* 31: 869-98.

[5] AIKEN.A.R.A, J.G.SCOTT, R.GOMPERTS, J.TRUSSELL, M.WORRELL AND C.E.AIKEN (2016) "Requests for Abortion in Latin America Related to Concern about Zika Virus Exposure," *New England Journal of Medicine* 375: 396-8.

[6] ALMOND.D (2006) "Is the 1918 Influenza Pandemic Over? Long-term Effects of In Utero Influenza Exposure in the Post-1940 US Population," *Journal of Political Economy* 114: 672-712.

[7] ALMOND.D AND J.CURRIE (2011) "Killing Me Softly: The Fetal Origins Hypothesis," *Journal of Economic Perspectives* 25: 153-72.

[8] ANDERBERG.D, A.CHEVALIER AND J.WADSWORTH (2011) "Anatomy of a Health Scare: Education, Income and the MMR Controversy in the UK," *Journal of Health Economics* 30: 515-30.

[9] AULD.M.C, E.P.FENICHEL AND F.TOXVAERD (2025) "The Economics of Infectious Disease," *Journal of Economic Literature*, forthcoming

[10] BACKER.J.A AND J.WALLINGA (2016) "Spatiotemporal Analysis of the 2014 Ebola Epidemic in West Africa," *PLOS Computational Biology.*

[11] BAHAMONDES.L, M.ALI, I.MONTEIRO AND A.FERNANDES (2016) "Contraceptive Sales in the Setting of the Zika Virus Epidemic," *Human Reproduction* 32: 88-93.

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.

[12] BANDIERA.O, N.BUEHREN, M.GOLDSTEIN, I.RASUL AND A.SMURRA (2025) "Safe Spaces for Teenage Girls in a Time of Crisis," *Journal of the European Economic Association*, forthcoming.

[13] BARBEITO-ANDRES.J ET AL. (2020) "Congenital Zika Syndrome is Associated with Maternal Protein Malnutrition," *Science Advances* 6: eeaw6284.

[14] BASSI.V AND I.RASUL (2017) "Persuasion: A Case Study of Papal Influences on Fertility-Related Beliefs and Behavior," *American Economic Journal: Applied Economics* 9: 250-302.

[15] BENNETT.D, C.F.CHIANG AND A.MALANI (2015) "Learning During a Crisis: The SARS Epidemic in Taiwan," *Journal of Development Economics* 112: 1-18.

[16] BENNETT.D, S.A.A.NAQVI AND W.P.SCHMIDT (2018) "Learning, Hygiene, and Traditional Medicine," *Economic Journal* 128: F545-74.

[17] BORGES.A.L.V ET AL. (2018) "Women's Reproductive Health Knowledge, Attitudes and Practices in Relation to the Zika Virus Outbreak in Northeast Brazil," *PlosOne* 13:e0190024.

[18] BRASIL.P *et al.* (2016) "Zika Virus Infection in Pregnant Women in Rio de Janeiro," *New England Journal of Medicine* 375: 2321-34.

[19] BRITO.C (2015) "Zika Virus: A New Chapter in the History of Medicine," *Acta Médica Portuguesa* 28: 679-80.

[20] CASTRO.M.C, Q.C.HAN, L.R.CARVALHO, C.G.VICTORA AND G.V.A.FRANCA (2018) "Implications of Zika Virus and Congenital Zika Syndrome for the Number of Live Births in Brazil," *PNAS* 115: 6177-82.

[21] CAUCHEMEZ.S *et al.* (2016) "Association Between Zika Virus and Microcephaly in French Polynesia, 2013-15: A Retrospective Study," *Lancet* 387: 2125-32.

[22] CAWLEY.J AND C.J.RUHM (2012) "The Economics of Risky Health Behaviors," in M.V.Pauly, T.G.Mcguire and P.Barros (eds.) *Handbook of Health Economics Vol.2*, New York: Elsevier.

[23] CHAN.T.Y, B.H.HAMILTON AND N.W.PAPAGEORGE (2016) "Health, Risky Behaviour and the Value of Medical Innovation for Infectious Disease," *Review of Economic Studies* 83: 1465-510.

[24] BORGES.A.L.V AND R.Z.COUTINHO (2021) "Health Knowledge About Zika Virus: Brazil Aspects," in C.R.Martin *et al.* (eds.) *Zika Virus Impact, Diagnosis, Control, and Models*, Academic Press.

[25] CURRIE.J AND H.SCHWANDT (2014) "Short- and Long-term Effects of Unemployment on Fertility," *PNAS* 111: 14734-9.

[26] CURRIE.J, B.GRENFELL AND J.FARRAR (2016) "Beyond Ebola: The Ebola Epidemic Provides Lessons for how to Respond to Future Epidemics," *Science* 351(6275): 815-6.

[27] CHRISTENSEN.D, O.DUBE, J.HAUSHOFER, B.SIDDIQI AND M.VOORS (2021) "Building Resilient Health Systems: Experimental Evidence from Sierra Leone and the 2014 Ebola Outbreak," *Quarterly Journal of Economics* 136: 1145-98.

[28] CORTES.DM GAMBOA.L.F AND P.RODRIGUEZ-LESMES (2020) Contraception, Intra-household Behaviour and Epidemic: Evidence from the Zika Crisis in Colombia, IZA DP18443.

[29] DEHEJIA.R AND A.LLERAS-MUNEY (2004) "Booms, Busts, and Babies' Health," *Quarterly Journal of Economics* 119: 1091-30.

[30] DINIZ.D, M.MEDEIROS AND A.MADEIRO (2017) "Brazilian Women Avoiding Pregnancy During Zika Epidemic," *Journal of Family Planning and Reproductive Health Care* 48: 80.

[31] DORSEY.E.R, E.OSTER AND IRA.SHOULSON (2013) "Optimal Expectations and Limited Medical Testing: Evidence from Huntington's Disease," *American Economic Review* 103: 804-30.

[32] EVANS.D.K, M.P.GOLDSTEIN AND A.POPOVA (2015) "Health-care Worker Mortality and the Legacy of the Ebola Epidemic," *Lancet Global Health* 3: e439-40.

[33] FLUCKIGER.M, M.LUDWIG AND A.SINA ONDER (2019) "Ebola and State Legitimacy," *Economic Journal* 129: 2064-89.

[34] FOGLI.A AND L.VELDKAMP (2021) "Germs, Social Networks and Growth," *Review of Economic Studies* 88: 1074-100.

[35] GAMBOA.L.F AND P.R.LESMES (2019) "The Fertility-inhibiting Effect of Mosquitos: Socioeconomic Differences in Response to the Zika Crisis in Colombia," *Economics and Human Biology* 35: 63-72.

[36] GEOFFARD.P-Y AND T.PHILIPSON (1996) "Rational Epidemics and Their Public Control," *International Economic Review* 37: 603-24.

[37] HAUSHOFER.J AND C.J.E.METCALFE (2020) Combining Behavioral Economics and Infectious Disease Epidemiology to Mitigate the COVID-19 Outbreak, mimeo, Princeton.

[38] JOHANSSON.M.A, L.MIER-Y-TERAN-ROMERO, J.REEFHUIS, S.GILBOA AND S.L.HILLS (2016) "Zika and the Risk of Microcephaly," *New England Journal of Medicine* 375: 1-4.

[39] KERMACK.W.O AND A.G.MCKENDRICK (1927) "A Contribution to the Mathematical Theory of Epidemics," *Proceedings of the Royal Society of London A* 115: 700-21.

[40] KREMER.M (1996) "Integrating Behavioral Choice into Epidemiological Models of AIDS," *Quarterly Journal of Economics* 111; 549-73.

[41] KREMER.M AND R.GLENNERSTER (2012) "Improving Health in Developing Countries: Evidence from Randomized Evalautions," in M.V.Pauly, T.G.Mcguire and P.Barros (eds.) *Handbook of Health Economics Vol.2*, New York: Elsevier.

[42] LAKDAWALLA.D, N.SOOD AND D.GOLDMAN (2006) "HIV Break-throughs and Risky Sexual Behavior," *Quarterly Journal of Economics* 121: 1063-102.

[43] MAFFIOLI.E (2021) "The Political Economy of Health Epidemics: Evidence from the Ebola Outbreak," *Journal of Development Economics* 151: 102651.

[44] MARSTON.H.D, N.LURIE, L.L.BORIO AND A.S.FAUCI (2016) "Considerations for Developing a Zika Virus Vaccine," *New England Journal of Medicine* 375: 1209-12.

[45] MARTELETO.L.J, A.WEITZMAN, R.A.COUNTINHO AND S.V ALVES (2017) "Women's Reproductive Intentions and Behaviors during the Zika Epidemic in Brazil," *Population and Development Review* 43: 199-227.

[46] MARTELETO.L ET AL. (2022) Fertility Trends During Successive Novel Infectious Disease Outbreaks: Zika and COVID-19 in Brazil, Cadernos de Saúde Pública 38, EN230621.

[47] MESSINA.J.P ET AL. (2016) "Mapping Global Environmental Suitability for Zika Virus," *eLife* 2016;5:e15272.

[48] MLAKAR.J *et al.* (2016) "Zika Virus Associated with Microcephaly," *New England Journal of Medicine* 374: 951-8.

[49] OLIVEIRA MELO.A.S *et al.* (2016) "Zika Virus Intrauterine Infection Causes Fetal Brain Abnormality and Microcephaly: Tip of the Iceberg?," *Ultrasound Obstet. Gynecol.* 47: 6-7.

[50] OSTER.E (2018) "Does Disease Cause Vacciantion? Disease Outbreaks and Vaccination Response," *Journal of Health Economics* 57: 90-101.

[51] PAHO/WHO (2015) *Epidemiological Alert: Zika Virus Infection*, Geneva, Switzerland.

[52] PEDROSA.C.S.G ET AL. (2019) "The Cyanobacterial Saxitoxin Exacerbates Neural Cell Death and Brain Malformations Induced by Zika Virus," *bioRxiv* 755066.

[53] PETERSEN.L.R, D.J.JAMIESON, A.M.POWERS AND M.A.HONEIN (2016) "Zika Virus," *New England Journal of Medicine* 374: 1552-63.

[54] PHILIPSON.T AND R.A.POSNER (1993) *Private Choices and Public Health: The AIDS Epidemic in an Economic Perspective*, Cambridge: Harvard University Press.

[55] PHILIPSON.T (2000) "Economic Epidemiology and Infectious Diseases," in A.J.Culyer and J.P.Newhouse (eds.) *Handbook of Health Economics Vol.1B*, New York: Elsevier.

[56] QUINTENA-DOMEQUE.C, J.R.CARVALHO AND V.H. DE OLIVEIRA (2018) "Zika Virus Prevalence, Correlates, and Preventive Behaviors: New Evidence from Survey Data," *Economics & Human Biology* 30: 14-23.

[57] RANGEL.M.A, J.NOBLES AND A.HAMOUDI (2020) "Brazil's Missing Infants: Zika Risk Changes Reproductive Behavior," *Demography* 57: 1647-80.

[58] RASMUSSEN.S.A, D.J.JAMIESON, M.A.HONEIN AND L.R.PETERSEN (2016) "Zika Virus and Birth Defects - Reviewing the Evidence for Causality," *New England Journal of Medicine* 374: 1981-7.

[59] RASUL.I (2020) "The Economics of Viral Outbreaks," *American Economic Association*, Papers and Proceedings 110: 265-68.

[60] RIBEIRO.B, S.HARTLEY, B.NERLICH AND R.JASPAL (2018) "Media Coverage of the Zika Crisis in Brazil: The Construction of a 'War' Frame that Masked Social and Gender Inequalities," *Social Science and Medicine* 200: 137-144.

[61] RICE.M.E *et al.* (2018) "Vital Signs: Zika-Associated Birth Defects and Neurodevelopmental Abnormalities Possibly Associated with Congenital Zika Virus Infection – U.S. Territories and Freely Associated States, 2018," *MMWR* August 7th, 2018, CDCP.

[62] SMITH.K.F, M.GOLDBERG, S.ROSENTHAL, L.CARLSON, J.CHEN, C.CHEN AND S.RAMACHANDRAN (2014) "Global Rise in Human Infectious Disease Outbreaks," *Journal of the Royal Society Interface* 11: 20140950.

[63] TAN.P.N AND T.PANG (2021) "Residence in Infected Neighborhoods and Fertility Decline During the Zika Epidemic in Singapore," *Population and Environment* 43: 393-422.

[64] THOMAS.S.J, M.L'AZOU, A.D.T.BARRETT AND N.A.C.JACKSON (2016) "Fast-track Zika Vaccine Development - Is it Possible?," *New England Journal of Medicine* 375: 1212-6.

[65] TRIUNFOL.M (2016) "A New Mosquito-Borne Threat to Pregnant Women in Brazil," *Lancet* 16: 156-7.

[66] VISCUSI.W.K (1990) "Do Smokers Underestimate Risks?," *Journal of Political Economy* 98: 1253-69.

[67] WORLD BANK (2017) *From Panic and Neglect to Investing in Health Security: Financing Pandemic Preparedness at a National Level*, Washington DC: World Bank Group.

[68] ZWANE.A ET AL. (2011) "Being Surveyed Can Change Later Behavior and Related Parameter Estimates," *Proceedings of the National Academy of Sciences* 108: 1821-6.

Table 1: Conceptions, Behavior During Pregnancy and Microcephaly

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

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

	Pre-alert, pre-epidemic (control)		Post-alert, pre-epidemic (control)		Pre-Alert, Zika epidemic (treated)		Post-Alert, Zika epidemic (treated)		Pre-post difference in epidemic year relative to earlier years	Std. err	[p-value]
Estimated Dates of Conception:	**May-Oct 2013 and May-Oct 2014**		**Nov 2012-Apr 2013 and Nov 2013-Apr 2014**		**May-Oct 2015**		**Nov 2014-Apr 2015 and Nov 2015-Apr 2016**				
	Mean	Std. dev	Mean	Std. dev	Mean	Std. dev	Mean	Std. dev			
A. Pregnancy											
Conception Rate	4.24	(.990)	3.91	(1.02)	4.19	(.979)	3.57	(.985)	-.296	(.035)	[.000]
B. Behavior During Pregnancy											
Pregnancy Test Rate	6.39	(20.2)	6.32	(18.1)	12.4	(30.2)	14.2	(32.8)	-.197	(.776)	[.802]
Ultrasound Rate	248	(355)	247	(267)	250	(275)	275	(289)	22.5	(3.06)	[.000]
Abortion Rate	163	(173)	164	(157)	166	(154)	174	(166)	7.81	(2.49)	[.004]
C. Birth Outcomes											
Microcephaly Rate	.061	(1.16)	.061	(1.51)	.830	(4.50)	.530	(3.58)	-1.00	.404	[.019]
# of City-month observations	56,776		32,726		27,550		26,401				
# of birth records	3,039,169		1,401,357		1,503,802		1,278,138				

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 pre-post difference in the epidemic year relative to earlier years is calculated from the corresponding OLS regression equation where we cluster standard errors by state. Outcomes in Panels A and C 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. In Panel C, the outcome is measured at the date of birth (and so does not correspond to month of conception).

Table 2: Preventive Responses - 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

Month of Conception	**(1) City Fixed Effects**	**(2) Month Fixed Effects**	**(3) Month and City Fixed Effects**	**(4) Temperature Controls**	**(5) State Specific Trends**	**(6) State Specific Trends (Squared)**	**(7) City Specific Trends**	**(8) Regions**
Zika$_t$, Pre-Alert (β_1)	-.044*	-.044*	-.044*	-.013	-.087***	-.087***	-.087***	-.005
	(.023)	(.023)	(.023)	(.019)	(.021)	(.021)	(.022)	(.018)
Zika$_t$, Post-Alert (β_2)	-.340***	-.339***	-.340***	-.319***	-.393***	-.393***	-.393***	
	(.030)	(.030)	(.030)	(.032)	(.034)	(.034)	(.035)	
Zika$_t$ Post-Alert x North East								-.424***
								(.090)
Zika$_t$, Post-Alert x North								-.145***
								(.050)
Zika$_t$, Post-Alert x South East								-.311***
								(.029)
Zika$_t$, Post-Alert x Centre West								-.352***
								(.056)
Zika$_t$, Post-Alert x South								**[omitted]**
Impact of the alert: β_2-β_1	-.296***	-.296***	-.296***	-.306***	-.305***	-.306***	-.305***	
	(.035)	(.035)	(.035)	(.032)	(.031)	(.031)	(.032)	
	[-.368, -.222]	[-.367, -.223]	[-.368, -.222]	[-.371, -.241]	[-.369, -.242]	[-.369, -.242]	[-.370, -.240]	
Baseline Mean (% 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	Yes
Month of Conception Fixed Effects	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time Varying Controls (City-Month)	No	No	No	Yes	Yes	Yes	Yes	Yes
Adjusted R-squared	.570	.078	.593	.601	.605	.605	.617	.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, we show 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: Mitigatory Responses During Pregnancy

Dependent variables: Rates per 1,000 women pregnant in the last 3 city-months

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

Standard errors clustered by state in parentheses

	(1) Pregnancy Test		**(2) Ultrasound**		**(3) Abortion**		**(4) Abortion | Gestation > 20wks**
Month of Outcome	**All**	**Positive**	**All**	**Positive**	**All**	**Positive**	**Positive**
May_Jul x Zika$_t$ (Pre-Alert, 1st Quarter)	5.55***	7.37***	3.22	3.50	3.88	4.62	-.110
	(1.24)	(1.24)	(5.70)	(6.48)	(4.11)	(4.86)	(.106)
Aug_Oct x Zika$_t$ (Pre-Alert, 2nd Quarter)	5.36***	7.07***	-4.44	-5.48	1.00	1.21	-.112
	(1.19)	(1.14)	(5.03)	(5.79)	(3.82)	(4.54)	(.067)
Nov_Jan x Zika$_t$ (Post-Alert, 1st Quarter)	4.41**	5.89***	9.92	11.24	5.37	6.50	-.165
	(1.20)	(1.29)	(6.18)	(6.89)	(3.26)	(3.82)	(.093)
Feb_April x Zika$_t$ (Post-Alert, 2nd Quarter)	5.95**	7.90***	34.80***	39.25***	15.76***	18.55***	.414***
	(1.83)	(2.07)	(4.99)	(5.51)	(3.06)	(3.56)	(.083)
Impact of the alert *(Post-Alert 2nd Quarter - Pre-Alert 2nd Quarter)*	.589	.833	39.2***	44.7***	14.7***	17.3***	.525***
	(.988)	(1.34)	(4.93)	(5.32)	(3.26)	(3.82)	(.104)
	[-1.44, 2.62]	[-1.92, 3.59]	[29.1, 49.3]	[33.7, 55.6]	[8.05, 21.4]	[9.48, 25.1]	[.310, .740]
Baseline Mean (% Impact)	6.39 (9.22%)	8.46 (9.85%)	248 (15.8%)	283 (15.8%)	164 (9.00%)	193 (8.96%)	3.54 (14.8%)
City of Residence Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month of Event Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time Varying Controls (City-Month)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R-squared	.547	.532	.562	.515	.755	.700	.708
Administrative Records Used	SIH/SIA	SIH/SIA	SIH/SIA	SIH/SIA	SIH/SIA	SIH/SIA	SIM
# of City-month observations	189,535	79,933	189,535	88,873	189,535	76,477	41,391

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 1000 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 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, we show 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

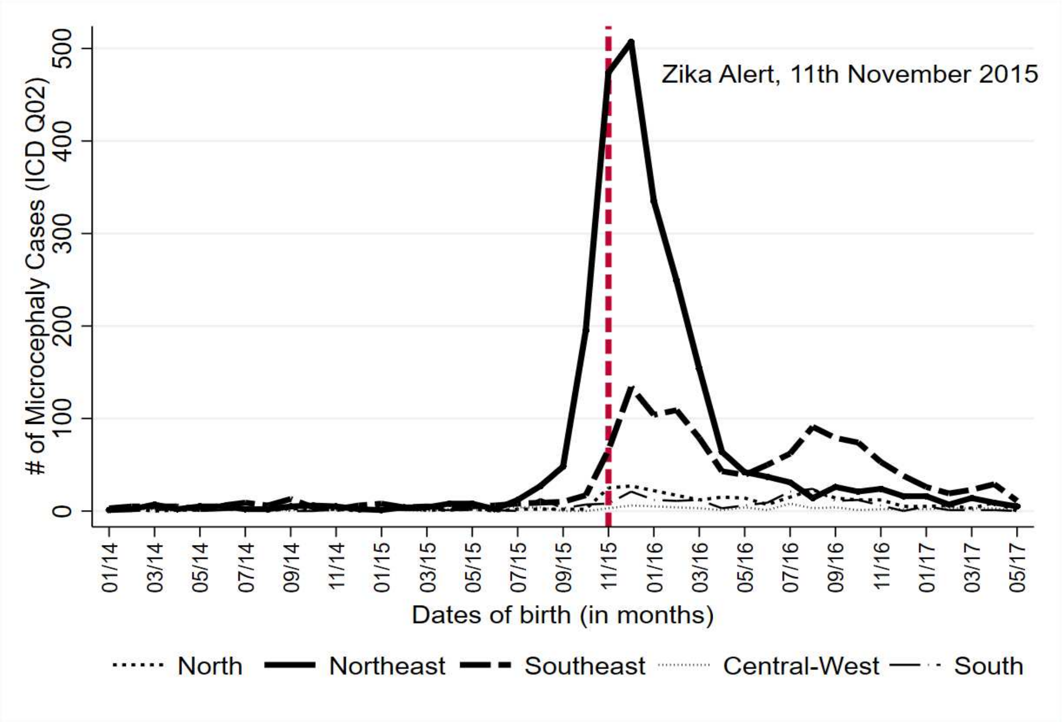
Dependent variables: Rates per 1,000 births in the city-month
City-month observations, weighed by 2012 city population of women aged 12-49
Standard errors clustered by state in parentheses

Month of Conception	(1) Microcephaly	(2) Microcephaly	(3) Low birth weight (< 2500g)	(4) Low birth weight (< 2500g)
Zika$_t$, Pre-Alert (β_1)	.808***	.790***	1.75***	1.32***
	(.166)	(.159)	(.375)	(.374)
Zika$_t$, Post-Alert (β_2)	-.239	1.11	.675*	-3.04
	(.271)	(1.81)	(.340)	(7.28)
Impact of the alert: β_2-β_1	-1.04**	.321	-1.07**	-4.36
	(.416)	(1.75)	(.448)	(7.27)
	[-1.90, -.191]	[-3.28 3.93]	[-1.99, -.158]	[-19.3 10.6]
Baseline Mean (% Impact)	.061 (1705%)	.061 (526%)	84.5 (1.26%)	84.5 (5.15%)
Month of Conception Fixed Effects	Yes	Yes	Yes	Yes
City of Residence Fixed Effects	Yes	Yes	Yes	Yes
Time-Varying Controls (City-Month)	Yes	Yes	Yes	Yes
Characteristics of Mothers (City-Month)	No	Yes	No	Yes
Adjusted R-squared	.032	.034	.056	.059
Administrative Records Used	SINASC	SINASC	SINASC	SINASC
# of City-month observations	190,423	189,461	190,423	189,461

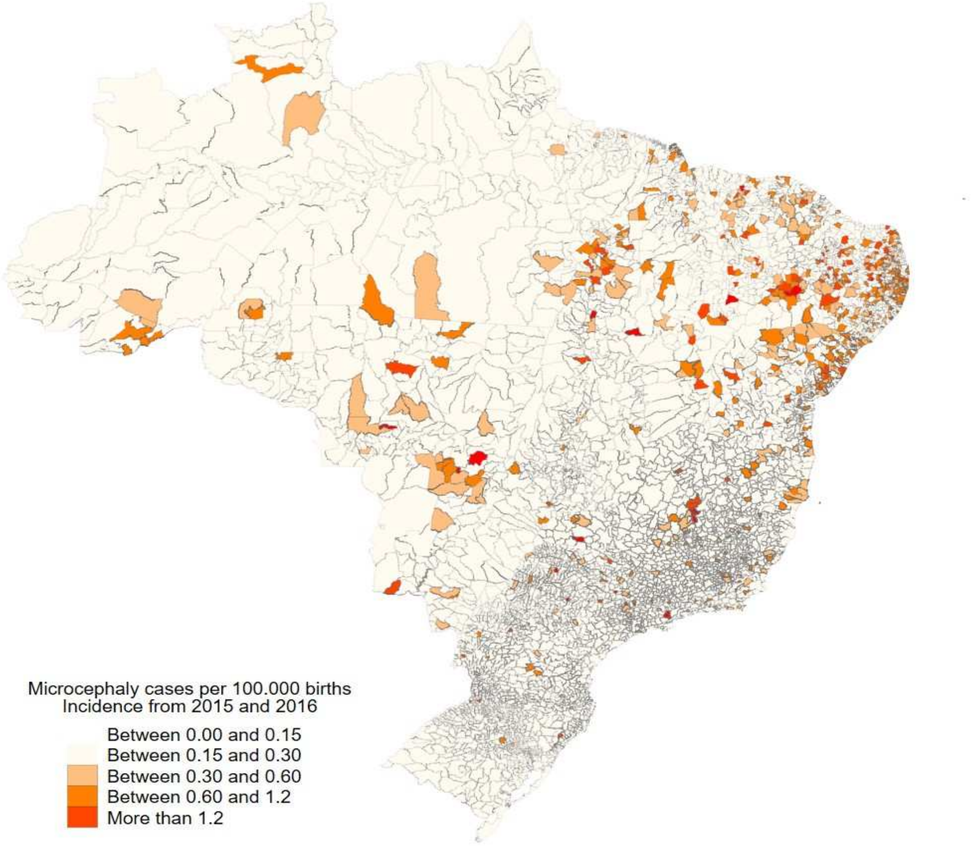
Notes: *** denotes significance at 1 percent, ** at 5 percent, and * at 10 percent level. All outcomes are derived from the SINASC birth records. Month refer to the month of conception. Pregnancy dates are recovered using information on the last menstruation date, and by subtracting the number of gestational weeks or categories of length of gestation from the exact date of birth. In Columns 1 and 2, 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). The mother characteristics controlled used in Columns 2 and 4 are an indicator for teenage mothers (≤18), non-white mothers, mothers with basic education (≤3 years of schooling), an indicator for missing father's age and maternal age (in years). Each variable is defined relative to an omitted category: mothers older than 18, mothers declaring themselves white, mothers with more than three years of schooling, and births with non-missing father's age. As the Table refers to outcomes at the city-month level, we average these mother characteristics at the city-conception date level. At the foot of each column, we show 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.

Figure 1: Microcephaly

A. Time Series of Microcephaly Cases, by Region



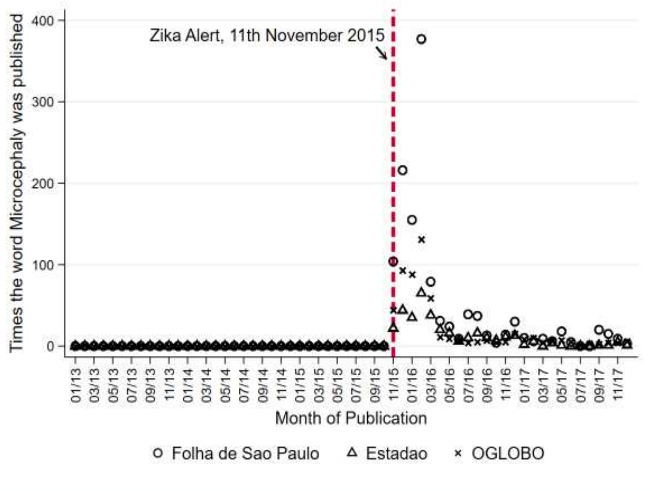
B. Spatial Incidence of Microcephaly Cases

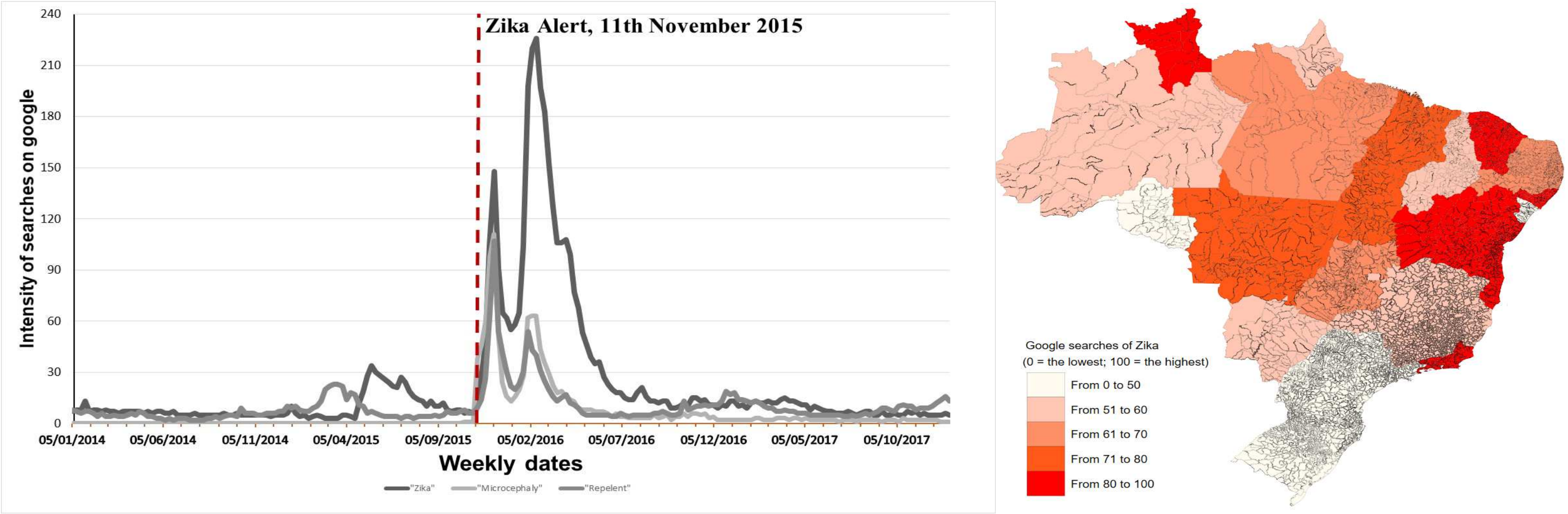


Notes: Panel A shows the number of microcephaly cases per region of birth from January 2014 until December 2016. The information of congenital malformation was generated using the international disease code Q02 referring to new borns with microcephaly. On the 11th November 2015 the Brazilian government 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





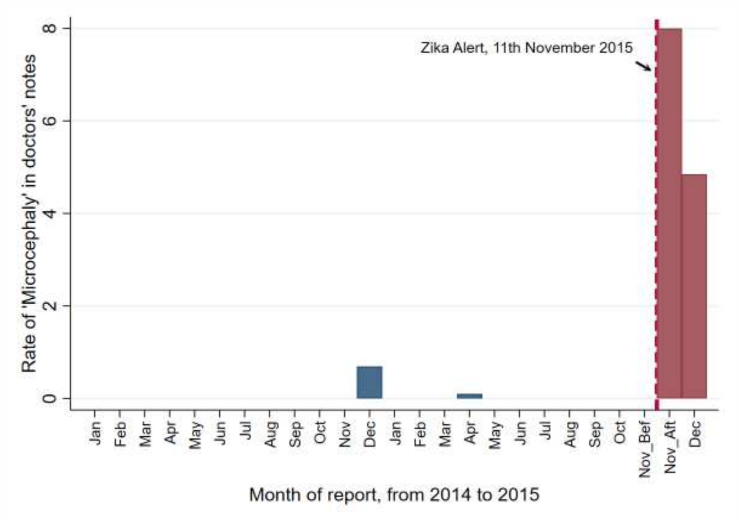
B. Google Searches for Zika, Microcephaly, Repellent

C. Spatial Variation in Google Searches for Zika

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 *Estadao*. 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 "Zica" 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.

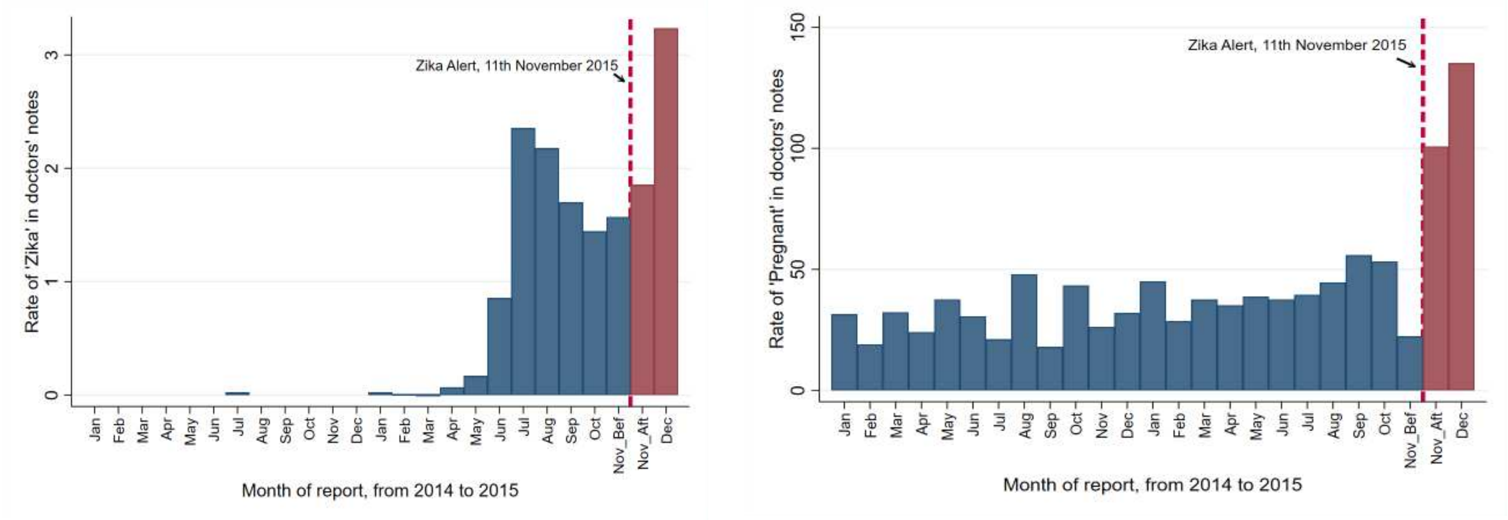
Figure 3: Doctors' Awareness

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



B. Incidence of "Zika" Written in Doctor's Notes

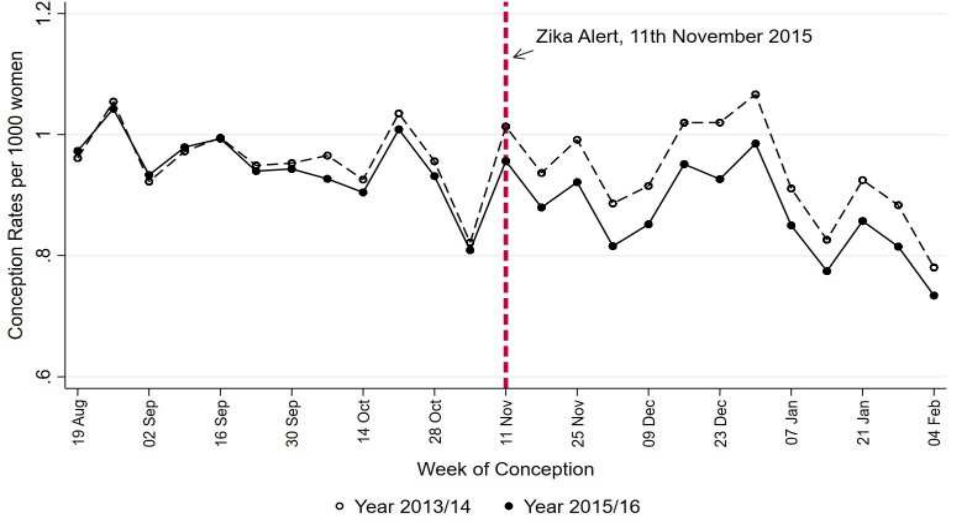
C. Incidence of "Pregnant" Written in Doctor's Notes

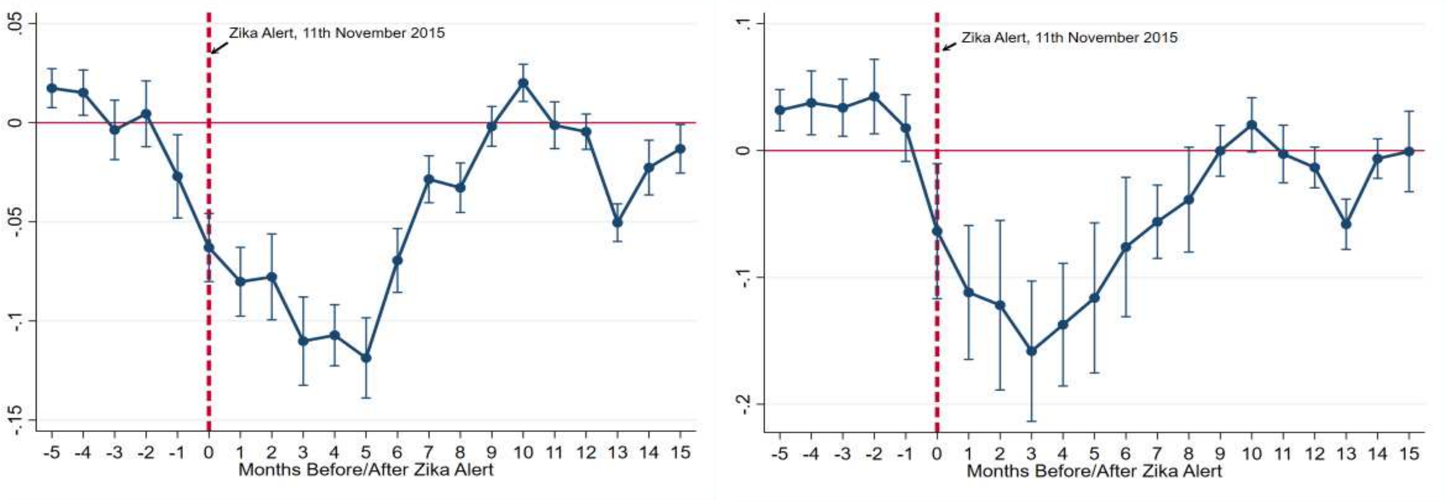


Notes: All data is constructed from information derived from the Sistema de Informação de Agravos de Notificação (SINAN), from January 2014 until December 2015. Doctor's notes are from doctors treating patients going to the hospital showing symptoms similar to dengue or patients suspected to have dengue. 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.

Figure 4: Dynamics of Conception

A. Conception Rates, by Week



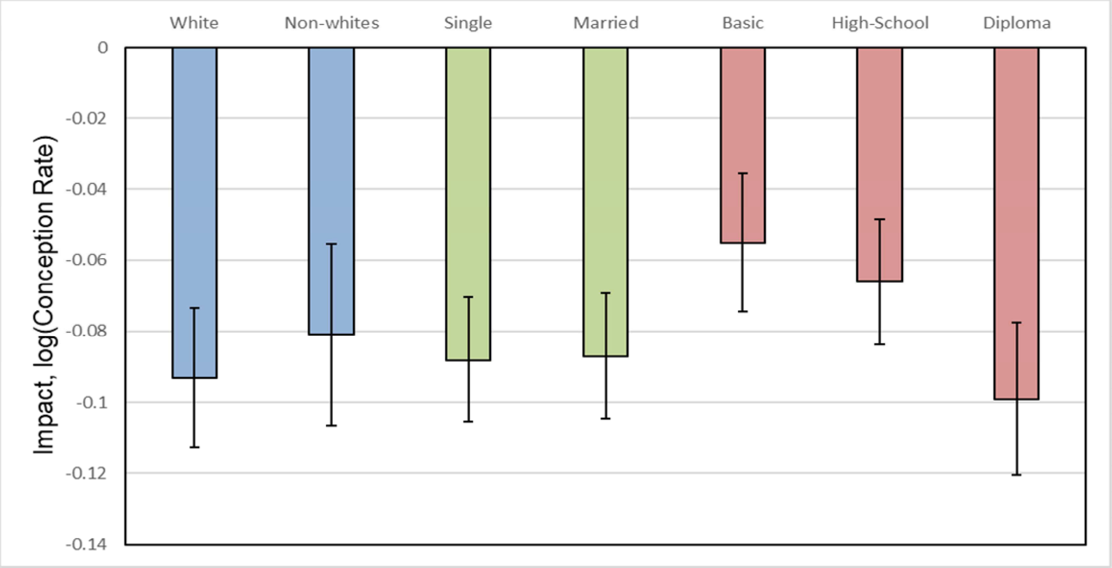

B. Dynamic Response Estimates

C. Dynamic Response Estimates (North East)

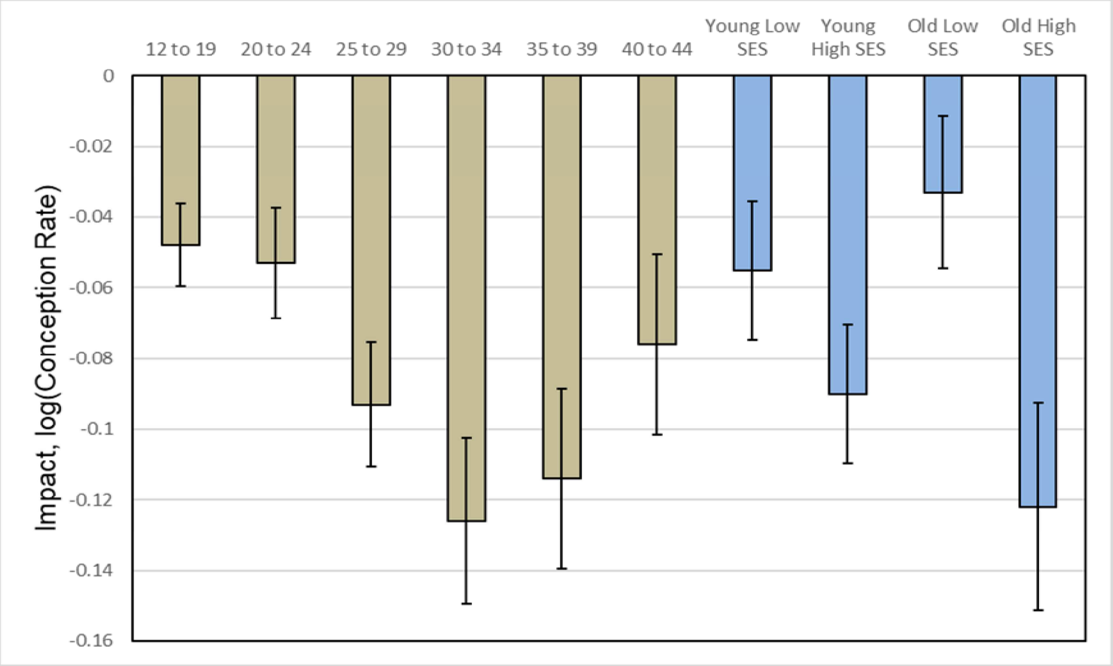
Notes: On the 11th November 2015 the Brazilian government officially announced the association between the upsurge of Zika and microcephaly in Northeastern Brazil. This is indicated by the vertical dashed line from Panels A to C. Panel A presents weekly changes in conceptions dates from the 33th to the 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 coefficients from 15 exclusive dummies on months since the Zika alert. Month -6 (six months prior to the alert being issues 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



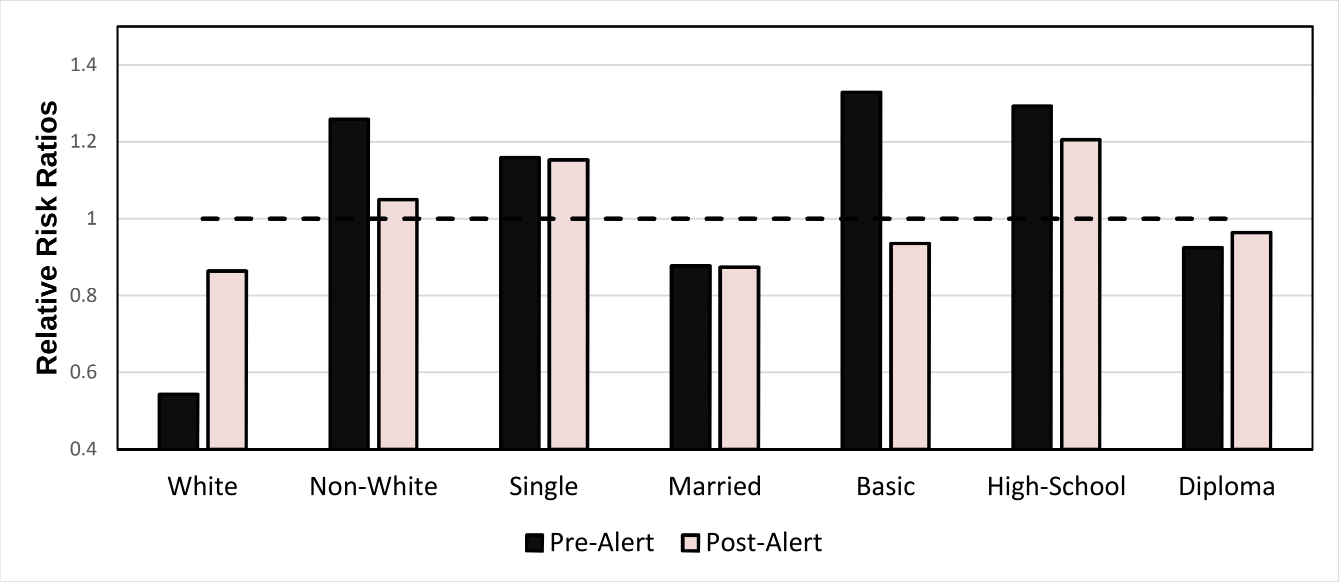
B. By Age and Socio-Economic Status



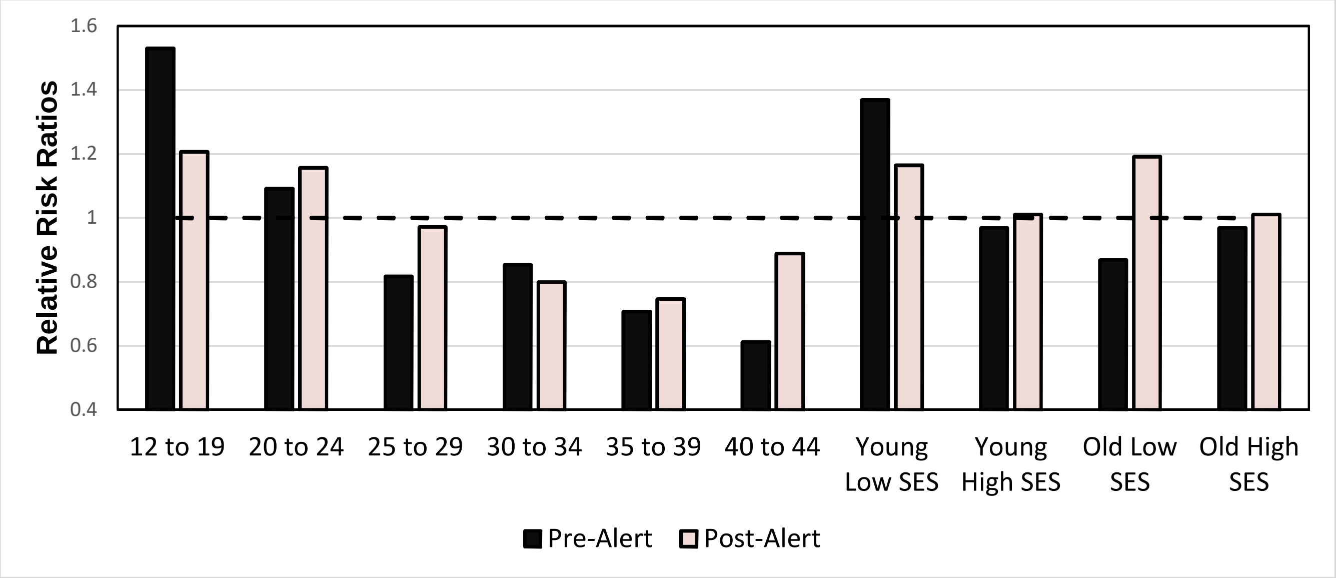
Notes: The Panels show the impacts of the Zika alert on conception rates among different subgroups, and the associated 90% confidence intervals. Non-white women are those reporting their race to be Black, Yellow, Parda and Native. The categories for mother's education include women with basic education (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



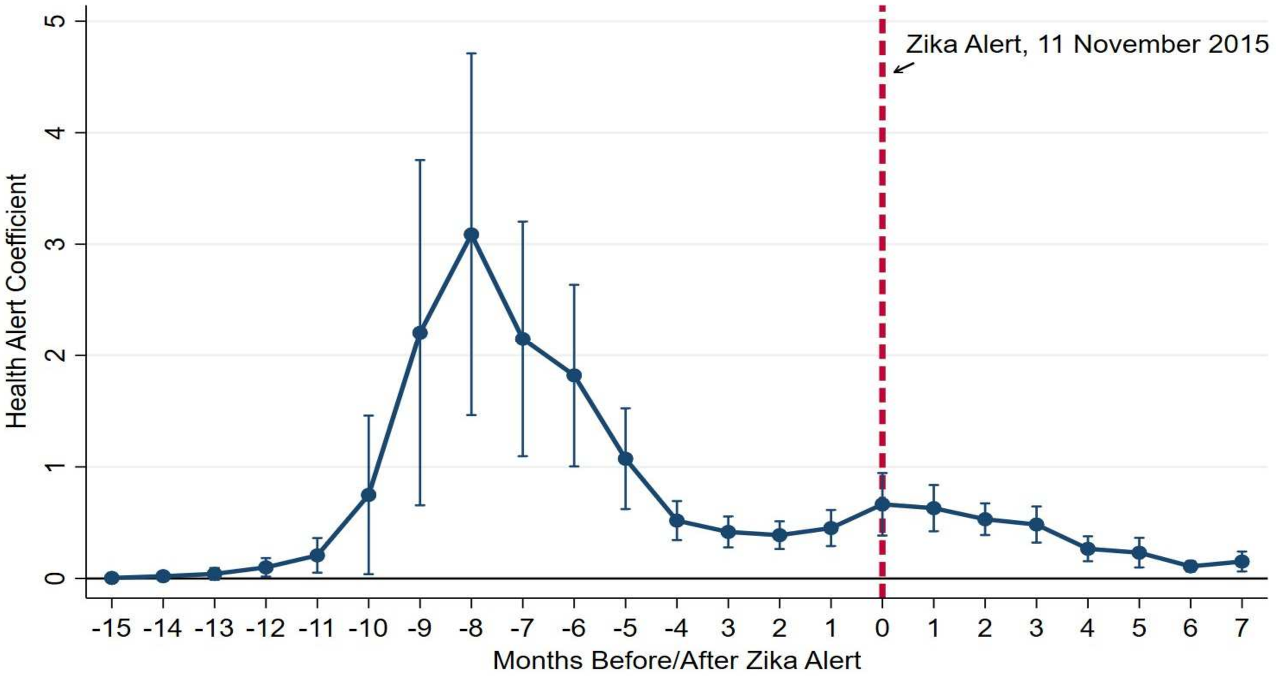
B. By Age and Socio-Economic Status



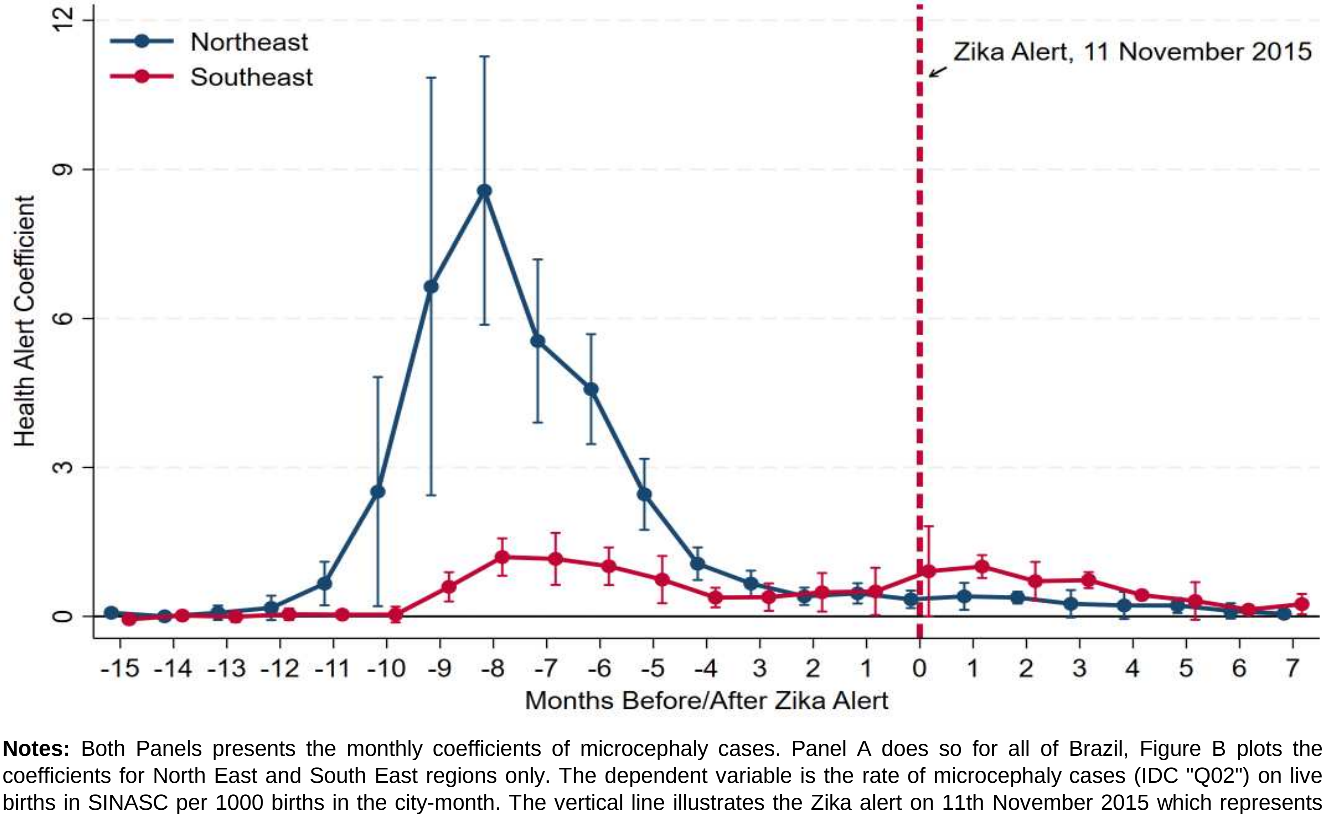
Notes: Figures A and B present the relative risk of having a child with microcephaly among different subgroups of mothers and their associated 95% confidence intervals. Pre-Alert periods in blue indicate (6 months before Zika Alert and Post Alert in red indicates 6 months after Zika Alert on 11 November 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.

Figure 7: Microcephaly, Dynamics

A. At Conception



B. By Region



Notes: Both Panels presents the monthly coefficients of microcephaly cases. Panel A does so for all of Brazil, Figure 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 use 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: 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

Standard errors clustered by state

	(1) Baseline	(2) Drop Month Fixed Effects	(3) Unweighted	(4) Drop Smaller Cities	(5) Include 2012 Data	(6) Alternative Numerator	(7) Health Personnel	(8) City of Residence and Birth Differ	(9) City of Residence and Birth Differ, Abortion Available	(10) City of Residence and Birth Differ, City Ultrasound Available
Zika$_t$, Pre-Alert (β_1)	-.013	.002	.004	-.013	.048*	-.010	-.006	.007**	-.017	-.015
	(.019)	(.018)	(.012)	(.020)	(.021)	(.022)	(.018)	(.002)	(.020)	(.020)
Zika$_t$, Post-Alert (β_2)	-.319***	-.303***	-.267***	-.321***	-.255***	-.350***	-.308***	.005**	-.324***	-.328***
	(.032)	(.031)	(.035)	(.033)	(.029)	(.035)	(.032)	(.002)	(.030)	(.033)
Impact of the alert: β_2-β_1	-.306***	-.305***	-.271***	-.308***	-.303***	-.340***	-.302***	-.001	-.306***	-.313***
	(.032)	(.031)	(.035)	(.032)	(.030)	(.035)	(.031)	(.001)	(.030)	(.033)
	[-.371, -.241]	[-.369, -.242]	[-.343, -.198]	[-.374, -.241]	[-.366, -.241]	[-.411, -.268]	[-.367 -.237]	[-.003, .001]	[-.369, -.243]	[-.382, -.242]
Baseline Mean (% 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%)	.309 (.323%)	4.26 (7.18%)	4.25 (7.34%)
City of Residency Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month of Conception Fixed effects	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time Varying Controls (City-Month)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R-squared	.601	.586	.357	.626	.582	.639	.602	.962	.707	.680
Administrative Records Used	SINASC	SINASC	SINASC	SINASC	SINASC	SINASC	SINASC & CNES	SINASC	SINASC & SIA/SIH	SINASC & SIA/SIH
# of City-month observations	190,423	190,423	190,423	156,235	255,129	190,423	190,406	190,423	76,557	88,950

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, we show 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: 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

	Population		Pregnant Women	
	(1) Baseline	(2) State Specific Trends	(3) Baseline	(4) State Specific Trends
Zika$_t$, Pre-Alert (β_1)	11.2***	.176	.357	-.355*
	(2.43)	(2.47)	(.238)	(.208)
Zika$_t$, Post-Alert (β_2)	10.2***	-1.00	-.771**	-1.51***
	(3.55)	(3.99)	(.365)	(.371)
Impact of the alert: β_2-β_1	-1.02	-1.18	-1.12***	-1.15***
	(1.85)	(1.88)	(.304)	(.295)
	[-4.83 2.78]	[-5.05 2.69]	[-1.75 -.502]	[-1.76 -.549]
Baseline Mean (% Impact)	114 (.894%)	114 (1.03%)	12.4 (9.03%)	12.4 (9.27%)
City of Residence Fixed Effects	Yes	Yes	Yes	Yes
Month Fixed Effects	Yes	Yes	Yes	Yes
Time Varying Controls (City-Month)	Yes	Yes	Yes	Yes
State Specific Linear Time Trend	No	Yes	No	Yes
Adjusted R-squared	.850	.860	.731	.743
Administrative Records Used	SIA & SIH	SIA & SIH	SIA & SIH	SIA & SIH
# of City-month observations	189,578	189,578	189,578	189,578

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 (IDC-10Z300, Z314, Z316, Z318, Z319), treating abortion (IDC-10 O200), hypertension during pregnancy (IDC-10 O100), assisting pregnant women (IDC-10 O350, O359, O361, O362, O363, O366, O369), and birth labor (IDC-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, precipitation (in millimeters), air humidity, maximum temperature (in Celsius) and min temperature (in Celsius). At the foot of each column, we show 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: Compositional Change in Those Giving Birth

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

Month of Conception	(1) % of Teenage mothers	(2) % of Non-White Mothers	(3) % of Missing Fathers Age	(4) % with Basic Education	(5) Average Mothers' Age (in years)
Zika$_t$, Pre-Alert (β_1)	-.009***	.007***	.037***	-.029***	.259***
	(.001)	(.002)	(.005)	(.002)	(.012)
Zika$_t$, Post-Alert (β_2)	-.005***	.012***	.039***	-.021***	.084**
	(.001)	(.002)	(.006)	(.002)	(.031)
Impact of the alert: β_2-β_1	.003***	.004***	.002	.007***	-.175***
	(.000)	(.001)	(.004)	(.001)	(.024)
	[.002, .005]	[.001, .008]	[-.008, .013]	[.003, .011]	[-.225, -.125]
Baseline Mean (% Impact)	.132 (2.27%)	.616 (.649%)	.527 (.379%)	.228 (3.07%)	26.3 (.665%)
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	.343	.939	.900	.647	.569
Administrative Records Used	SINASC	SINASC	SINASC	SINASC	SINASC
# of City-month observations	190,423	189,620	190,423	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, we show 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: Health Care Personnel Behavior

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

Standard errors clustered by state in parentheses

Month of Outcome	(1) Dengue Tests Administered to Pregnant Women	(2) Negative Dengue Test Results in Pregnant Women	(3) Inconclusive Dengue Test Results in Pregnant Women	(4) Diagnosed Cases of Zika	(5) Potential Cases of Zika	(6) Counseling on Contraception	(7) Cases of Eclampsia
Zika$_t$, Pre-Alert (β_1)	.017	.018	.000	.024**	.007*	.003	.266
	(.017)	(.017)	(.001)	(.011)	(.004)	(.002)	(.961)
Zika$_t$, Post-Alert (β_2)	.164*	.546***	.016***	.200***	.009**	.001	1.07
	(.088)	(.077)	(.003)	(.056)	(.004)	(.001)	(1.40)
Impact of the alert: β_2-β_1	.147*	.527***	.016***	.176***	.002	-.002	.805
	(.073)	(.073)	(.003)	(.054)	(.001)	(.001)	(1.01)
	[-.003, .298]	[.376, .678]	[.009, .023]	[.066, .286]	[-.0005, .005]	[-.005, .001]	[-1.27, 2.89]
Baseline Mean (% Impact)	.059 (249%)	.060 (878%)	.001 (1600%)	.012 (1466%)	.009 (22.2%)	.001 (200%)	33.0 (2.44%)
Rate Definition	Conceptions in the Previous 8 Months	Conceptions in the Previous 8 Months	Conceptions in the Previous 8 Months	100,000 population	100,000 population	Per 1000 Women	Conceptions in the Previous 8 city-months
Month of Event Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City of Residence Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time Varying Controls (City-Month)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R-squared	.051	.088	.002	.027	.367	.232	.794
Administrative Records Used	SINAN	SINAN	SINAN	SIH/SIA	SIH/SIA	SIH/SIA	SIH/SIA
# of City-month observations	97,059	97,059	97,059	193,331	193,331	193,331	189,535

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, 0213010330, 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, we show 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 A5: 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

Month of Outcome	**(1) Dengue Tests Administered to Pregnant Women**	**(2) Negative Dengue Test Results in Pregnant Women**	**(3) Inconclusive Dengue Test Results in Pregnant Women**
Zika$_t$, Pre-Alert (β_1)	.016	.006	-.000
	(.017)	(.016)	(.001)
Zika$_t$ Post-Alert x North East	.063	.520**	.017*
	(.047)	(.198)	(.009)
Zika$_t$, Post-Alert x North	.077**	.376***	.014**
	(.031)	(.112)	(.007)
Zika$_t$, Post-Alert x South East	.195	.530***	.018***
	(.165)	(.046)	(.005)
Zika$_t$, Post-Alert x Centre West	.156***	.450***	.014**
	(.044)	(.104)	(.006)
Zika$_t$, Post-Alert x South	**[omitted]**	**[omitted]**	**[omitted]**
Rate Definition	Conceptions in the Previous 8 Months	Conceptions in the Previous 8 Months	Conceptions in the Previous 8 Months
Month of Event Fixed Effects	Yes	Yes	Yes
City of Residence Fixed Effects	Yes	Yes	Yes
Time Varying Controls (City-Month)	Yes	Yes	Yes
Adjusted R-squared	.050	.083	.002
Administrative Records Used	SINAN	SINAN	SINAN
# of City-month observations	97,059	97,059	97,059

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 Transcriptase 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.

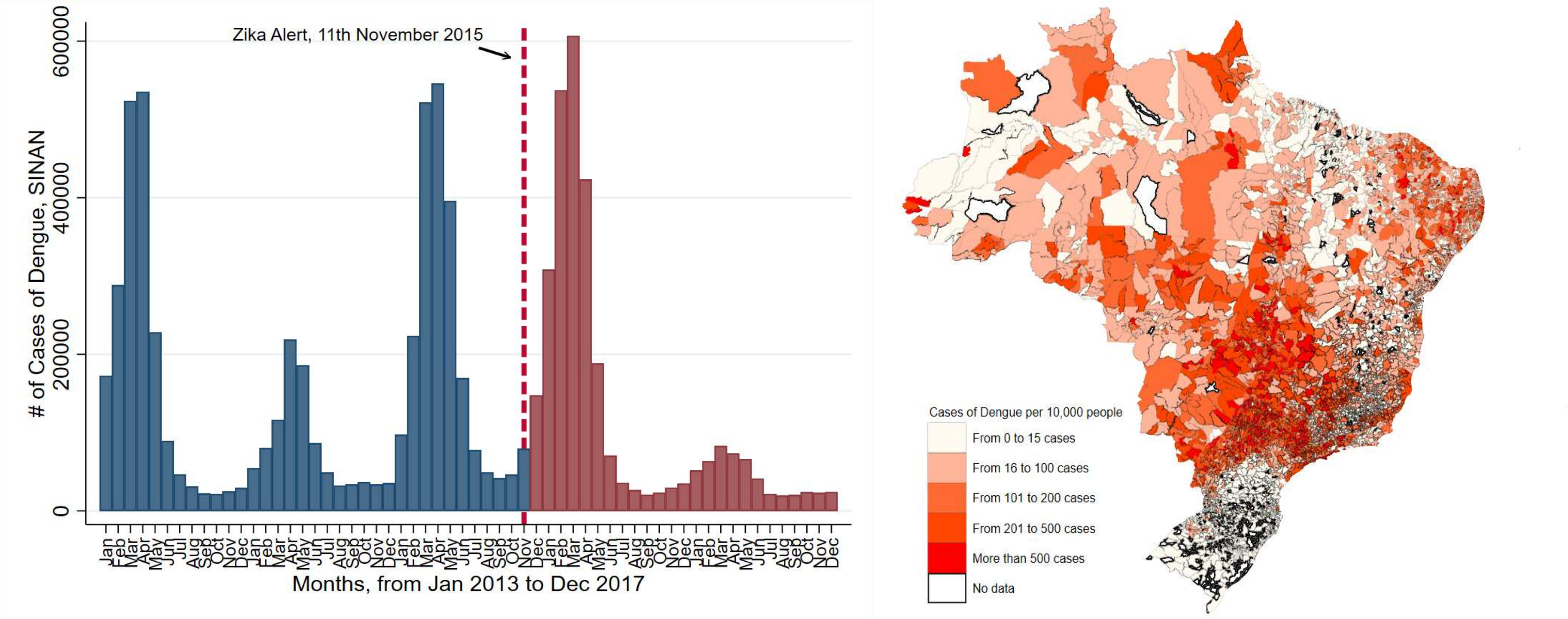


Figure A1: Dengue

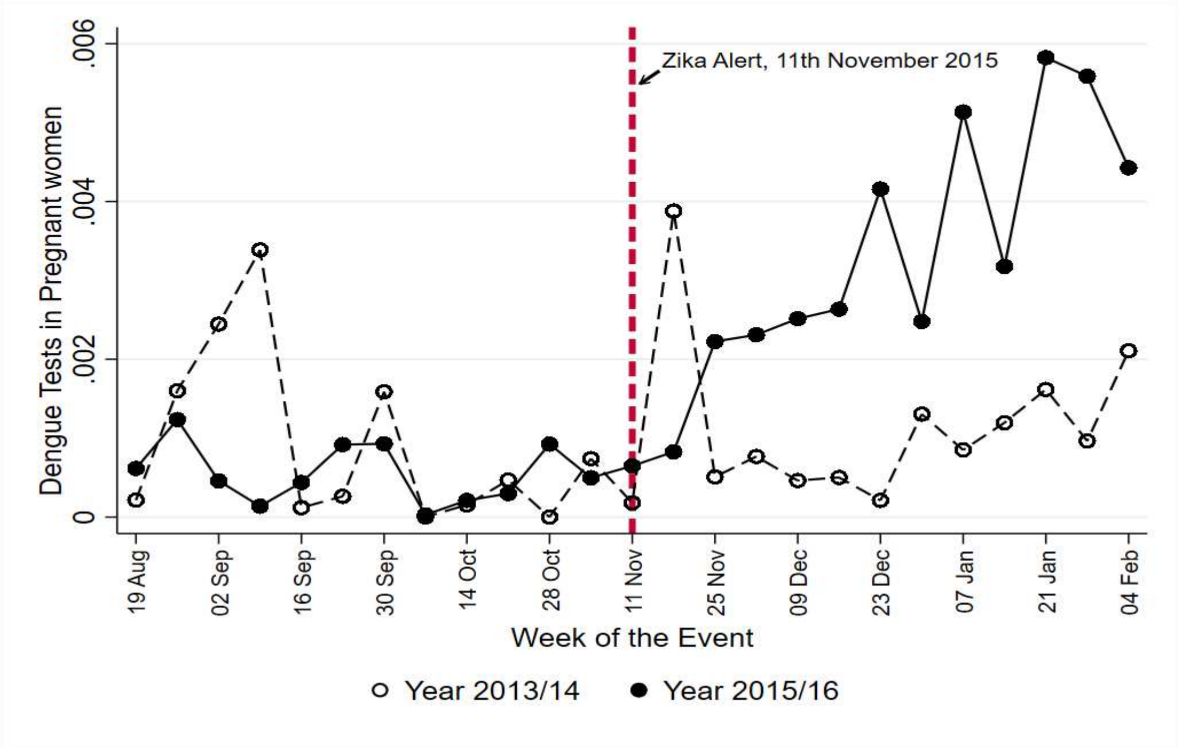
A. Temporal Variation in Suspected/Confirmed Dengue Cases (ICD = A91)

B. Spatial Variation in Dengue Incidence

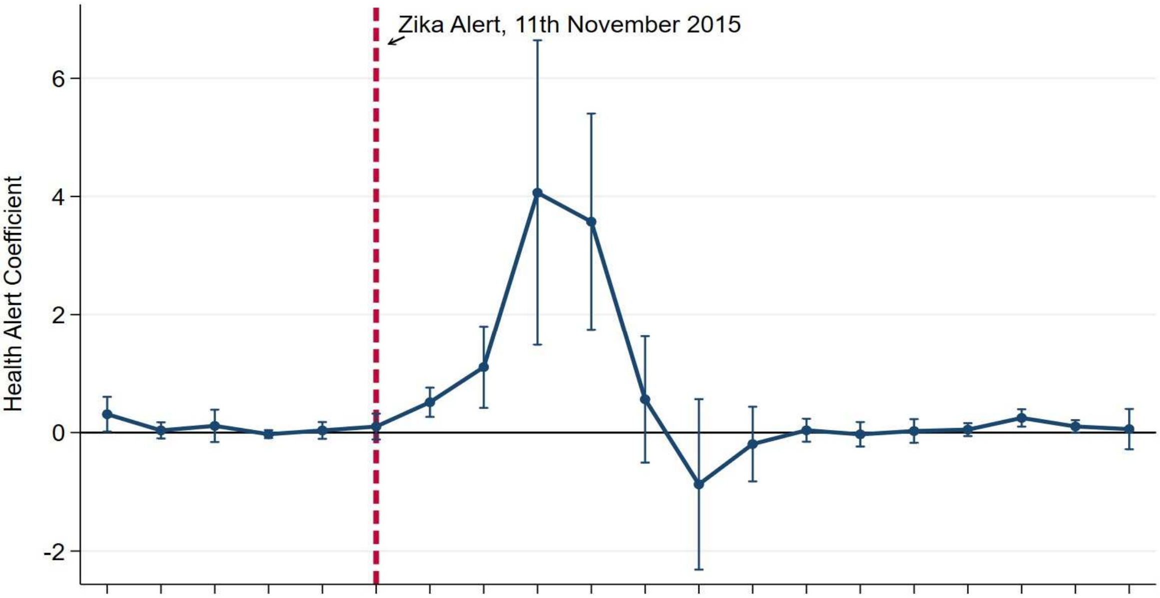
Notes: The time series in suspected or confirmed dengue cases is shown in Panel A, from SINAN administrative records. Panel B maps the incidence of dengue per 10,000 people living in cities, for suspected or confirmed cases during 2015 and 2016.

Figure A2: Administration of Dengue Tests to Pregnant Women

A. Dengue Tests, by Week

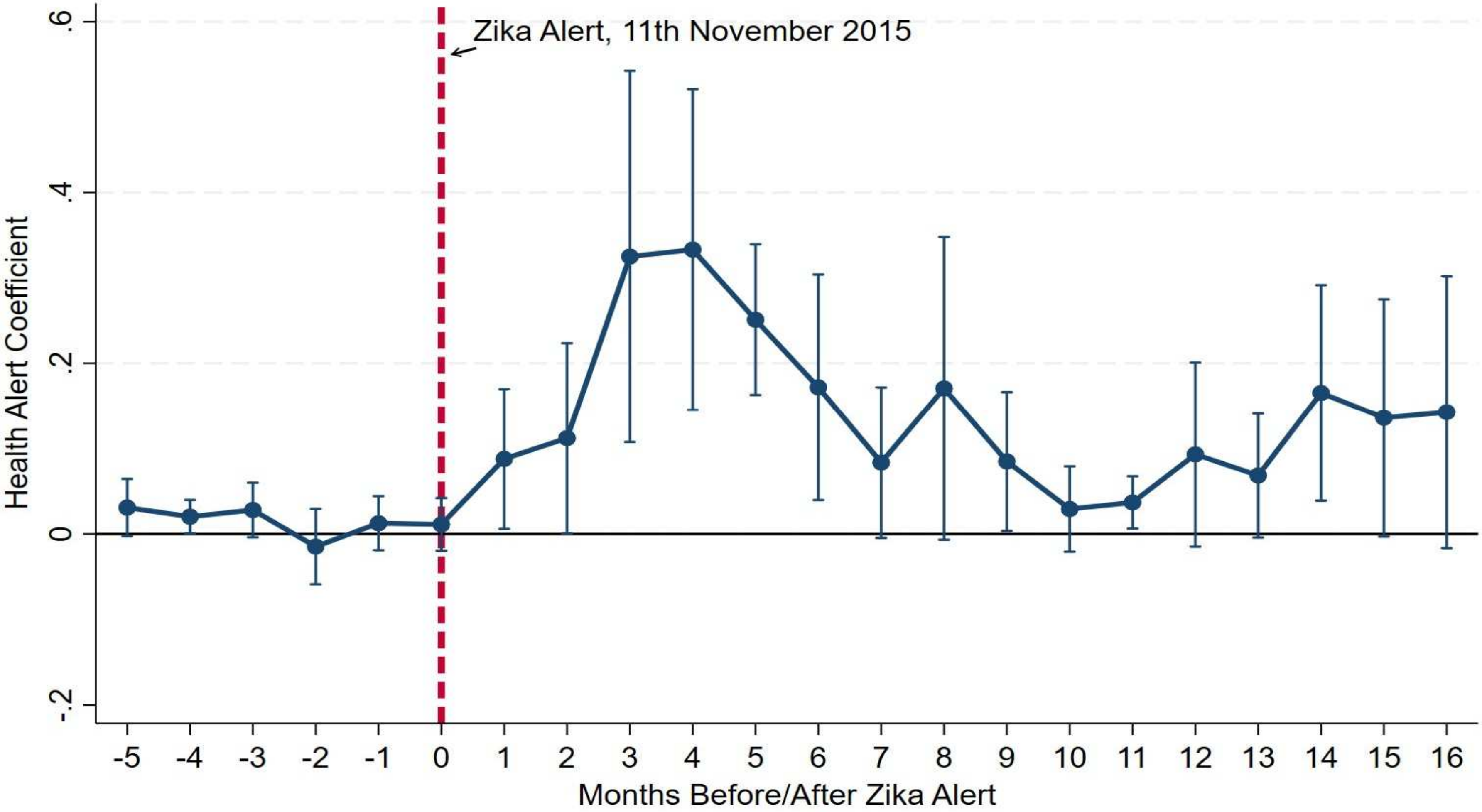


B. Dynamic Response Estimates



Notes: Panel A shows weekly changes in the rate of dengue tests on pregnant women from the 39th to the 51th 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 coefficients since ZIka Alert. The dependent variable is the indidence 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 x-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: 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 coefficient and the associated 90% confidence interval. Standard errors are clustered by state.