The Anatomy of a Public Health Crisis: Household and Health Sector Responses to the Zika Epidemic in Brazil[*]

Ildo Lautharte Junior Imran Rasul[†]

March 2019

Abstract

The global frequency and complexity of viral outbreaks is increasing. In 2015, Brazil experienced an epidemic caused by the Zika virus. This represents the first known association between a flavivirus and congenital disease, thus marking a 'new chapter in the history of medicine' [Brito 2015]. We use administrative records to document household and health personnel responses to the epidemic over two phases: (i) between May and October 2015, when it was known that Zika was in Brazil, but its symptoms were thought to be dengue-like and without consequence for those *in utero*; (ii) following an official alert on November 11th recognizing the link between Zika and congenital disease. On household behavior, we find a 7% reduction in pregnancies post-alert, a response triggered immediately after the alert, and driven by higher SES women. On responses during pregnancy, there is an increased use of ultrasounds (9%) and abortions (5%), especially late term abortions. These impacts are driven by mothers that conceived post-alert. There is a lack of response during pregnancy among mothers that conceived just pre-alert, despite their unborn children also being at risk. As a result, those conceived pre-alert are significantly more likely to be born with low birth weight, and the rise in microcephaly is concentrated in this cohort. On responses of health personnel, we document an increased administration of dengue tests to pregnant women post-alert (that lacking a formal test for Zika was the best approach to diagnosis), and no change in counseling on contraception for women seeking to become pregnant. Our results provide a rich picture of household and health personnel responses to an evolving epidemic. They suggest disseminating information about Zika is less effective among those already pregnant and at risk, but for those yet to conceive, the primary welfare cost of the epidemic is disease avoidance, as they move away from unconstrained fertility paths, or abort pregnancies.

JEL Classification: I12, J13.

---

[*] We thank Oriana Bandiera, Thiemo Fetzer, Caio Piza, Andrea Smurra, Anna Vitali, Guillermo Uriz-Uharte and seminar participants for valuable comments. All errors remain our own.

[†] Junior: University College London, i.junior@ucl.ac.uk; Rasul: University College London, i.rasul@ucl.ac.uk.

1 Introduction

Viruses and viral outbreaks have shaped the course of human history. Between 1980 and 2013, there were over $12,000$ recorded outbreaks of 215 human infectious diseases, comprising 44 million cases across 219 countries, with the frequency and diversity of viral outbreaks increasing over time [Smith *et al.* 2014]. The underlying drivers of this time trend have been an increase in the size, density and connectivity of human populations, mass displacements arising from conflict, and climate change.[1] The economic costs of outbreaks are severe: they can restrict economic exchange, alter social interactions and network structures, raise mortality in the short run, and impact morbidity, human capital accumulation and economic growth in the longer run [Almond 2006, Fogli and Veldkamp 2013]. Estimates suggest the annual global cost of moderately severe to severe pandemics is 0.7% of global income, greater than estimated costs of natural disasters, and comparable to those from climate change [World Bank 2017].[2]

We use detailed administrative records to study the impacts of a recent and important viral epidemic: the Zika epidemic in Brazil in 2015. What was most significant about this epidemic was that it represents the first ever known association between a flavivirus, carried by the *Aedes Aegypti* mosquito, and congenital diseases. It thus represents a 'new chapter in the history of medicine' [Brito 2015].[3] The *Aedes Aegypti* mosquito is familiar to Brazilians because it is the carrier for viruses including malaria and dengue. Annually, these mosquitoes infect two million Brazilians, and over 300 million globally [WHO 2014]. The congenital diseases identified to be related to the Zika virus in the 2015 epidemic included microcephaly: a neurological disorder among newborns in which the occipitofrontal circumference is smaller than that of other children of the same age, race, and sex. It is defined as a head circumference of two standard deviations below the mean for age and sex, or about less than the second percentile [WHO 2014].

The timeline of the epidemic was as follows. In March 2015, the WHO received notification from the Brazilian government regarding an illness transmitted by the *Aedes Aegypti* mosquito,

---

[1] Smith *et al.* [2014] analyze a novel 33-year dataset (1980-2013) that collated information on $12,102$ outbreaks of 215 human infectious diseases. They examine global temporal trends in the number of outbreaks, disease richness, disease diversity and per capita cases. Bacteria, viruses, zoonotic diseases (originating in animals) and those caused by pathogens transmitted by vector hosts are responsible for the majority of outbreaks. After controlling for disease surveillance, communications, geography and host availability, they find the number and diversity of outbreaks, and richness of causal diseases has increased significantly since 1980.

[2] The mortality toll of viruses alone is severe: over the last century, they have been responsible for more deaths than all armed conflict: smallpox has caused around 300 million deaths during the twentieth century, influenza has killed 100 million, and HIV has led to around 30 million deaths [Adda 2016 and citations therein].

[3] Following epidemiological convention, we label the crisis as an epidemic because it was a sudden increase in the number of cases of a disease above what is normally expected. As cases were reported throughout Brazil it is more severe than an outbreak (that is used to describe a limited geographic event). The Zika virus spread across countries in the Americas, so also constitutes a pandemic.

but not detected by standard tests. In April 2015 the first case of Zika virus (ZIKV) in continental America was confirmed. Until early November, it was thus known that Zika was present in Brazil but the perception was that it was a 'dengue-like' infection, and harmless to newborns. However, on November 11th the Brazilian government issued an alert emphasizing an upsurge in microcephaly in the North East of the country. This was the first time a potential connection between Zika and microcephaly was made. On November 17th, scientists confirmed the detection of ZIKV in the amniotic fluid of two pregnant women, whose foetuses had microcephaly [PAHO/WHO 2015].

The severity of the epidemic in Brazil deepened, and ZIKV spread rapidly across countries: a WHO communique in December stated a 20-fold increase in microcephaly in Brazil, and nine WHO member states had confirmed ZIKV circulation. The first recorded newborn with microcephaly in the US occurred in January 2016 and by February the WHO launched an alert stating microcephaly was an international concern. Brazil was the most affected country, with between $440,000$ and 1.3 million cases of ZIKV infection through to December 2015 [Mlakar *et al.* 2016].

We use a difference-in-difference (DD) research design to study the impact of the public health alert issued on November 11th, on the behaviors of households/women *and* health care personnel through Brazil. Public health alerts are a common policy response to outbreaks and epidemics, and indeed many public health interventions involve the dissemination or regulation of information to households. The variation our research design exploits are differences in outcomes between pre- and post-alert periods during the epidemic year when ZIKV was known to be in Brazil, with differences in the same pre- and post-alert periods in pre-epidemic years.

We conduct our analysis using multiple administrative data sources that provide near universal coverage of birth and hospital care statistics from all 27 states (including the federal district) and 5565 cities (municipalities) in Brazil from January 2013 onwards. We use administrative birth records that cover all 12 million live births in hospitals or homes from January 2013 to December 2017. These detail the exact date and location of birth, demographic characteristics of mothers, and birth outcomes such as birth weight and ICD-10 codes for congenital malformations. The data also records the estimated date of last menstruation, based on medical examinations. We use this to construct an estimated date of conception, and so consider responses among those cohorts that choose to conceive pre- and post-alert.

We examine behavioral responses during pregnancy by merging inpatient and outpatient administrative records. These cover all public hospitals and a subset of private hospitals that work with the National Health Service: our estimates are based on 400 million patient records, covering more than 70% of hospitalizations. These record the exact date and hospital of admission, ICD-10 codes are provided for primary and secondary reasons for admission, as well as codes for medical procedures undertaken. We use these records to measure post-alert changes in behavior during pregnancy such as the use of ultrasounds and abortions, as well as the incidence of Zika infection in the population as a whole.

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

To examine supply side responses to the epidemic, we examine behavioral responses among health care personnel using two administrative data sources: (i) the national system of notifiable diseases; (ii) inpatient-outpatient records that record procedures carried out on patients, as described above. Together these detail health personnel responses such as the use of tests for dengue (that absent a test for Zika was the best available alternative for diagnosis), and the provision of counselling to encourage contraceptive use.

Our results on household behavior chronologically sequenced through pregnancy are as follows. First, we find a significant reduction in pregnancy rates post-alert: the magnitude of the effect is 7.21% fewer pregnancies per month post-alert. This finding is robust to multiple checks for differential time trends over states and cities, and is precisely estimated: the 95% confidence interval rules out a reduction smaller than 5.7%. This response is also of economic significance, being equivalent to $18,000$ fewer children being conceived nationwide each month in the post-alert period, and the response represents 53% of natural variation in pregnancy rates across months of the year due to well known seasonality in pregnancies [Lam and Miron 1996].

On response dynamics: (i) in the weeks prior to the alert, weekly pregnancy 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 pregnancy rates opens up. In terms of longer term responses, we find significant falls in pregnancy rates for 9 months after the alert. These reductions rates reflect women moving away from their unconstrained fertility path, and so can have important consequences for their labor supply, the welfare of other household members, and longer term ability to complete desired levels of total fertility. As in Philipson [2000], we interpret the epidemic as a random 'tax' on behavior risking exposure, which thus distorts individuals' choices by inducing them to forego otherwise valuable activity. This disease avoidance is the first order welfare cost of the epidemic (that impacts far more individuals than those that go on to actually suffer congenital malformations through Zika).

The scale of the administrative data allows us to precisely identify that the reduction in pregnancies is driven by older and higher SES women. This fits the narrative that higher SES women were either better informed of the risks, or face lower costs of altering fertility timing. The implication is that the cohort of children conceived post-alert are likely to be negatively selected, in that they are born to younger and lower SES mothers relative to the counterfactual. We thus interpret later outcomes for this cohort as being partly driven by the selected sample of mothers that conceive despite the risks highlighted in the official alert.

On changes in behavior *during* pregnancy, the administrative records allow us to document that among those conceiving post-alert, there are behavioral changes during the first trimester of pregnancy. Specifically, there is an increased use of ultrasound (9%). On abortions, despite severe legal restrictions on abortion, officially recorded abortion rates are high pre-epidemic: around 16% of women pregnant in the previous three months have an abortion (partly reflecting the lack of contraceptive access in this context). Our DD design suggests this rises by a further 5% post-alert (corresponding to around $4,000$ more abortions per month post-alert). In terms of timing, there is a 15% increase in late term abortions.

Among mothers that conceive post-alert, the significant increase in abortions suggests a second stage of selection into birth outcomes (beyond selection into pregnancy).

For ultrasounds and abortions, both DD are driven by changes in behavior during pregnancy of those selected mothers that conceived post-alert, rather than changes in behavior among (non-selected) mothers that conceived pre-alert. This lack of behavioral response is despite the fact that children conceived pre-alert are obviously also at risk from ZIKV infection. This is so even among mothers that conceive just prior to the alert, and so have the opportunity to undergo an ultrasound or abortion in the first trimester of pregnancy. This lack of response is more in line with the kind of limited attention or endogenous belief formation that seems to explain many health behaviors outside of epidemics [Kremer and Glennerster 2012, Dorsey *et al.* 2013].

On birth outcomes, we find that children conceived post-alert are significantly more likely to be born premature, although the impact is small (1.7%). Birth weight is the most widely used indicator of neonatal health [Almond and Currie 2011]. We find that children conceived post-alert are significantly *less* likely to be low birth weight relative to those conceived pre-alert. While this is at first puzzling we need to distinguish between the two cohorts driving the DD, given the earlier results on the post-alert selection into pregnancy and abortion. Among those conceived pre-alert, the likelihood of low birth weight significantly increases relative to pre-epidemic years (by 2% of the baseline mean); among the select group of children conceived post-alert (i.e. among mothers that did not delay pregnancy) and that reached full term (i.e. among mothers that did not abort), the likelihood of low birth weight also rises relative to pre-epidemic years but by less (1% of the baseline mean).

The final set of birth outcomes examined are Zika-specific risks. We find a marked rise in cases of microcephaly for children conceived pre-alert (by 1324%). For the selected sample of children conceived post-alert, there is *no* significant difference in rates of microcephaly relative to children born in similar months in pre-epidemic years. The overall DD thus corresponds to a 1700% reduction in microcephaly rates among those conceived post-alert relative to those conceived pre-alert. Hence despite post-alert births being concentrated among younger and lower SES mothers, the findings on microcephaly are consistent with these mothers taking offsetting precautions to mitigate the risk of mosquito bites and hence Zika infection during pregnancy.

Our second set of results examine supply side responses within the health sector. These help us interpret whether the documented household responses might be driven by the behavior of health care personnel. When examining supply side responses to the alert, we reiterate that pre-alert, the common belief in Brazil was that Zika had dengue-like symptoms. We thus first examine the rate of dengue tests administered to pregnant women. We find a 249% increase in the use of dengue tests among pregnant women post-alert. On test outcomes, we document even larger percentage increases in negative dengue test results for pregnant women (878%), and in inconclusive test results (1600%). This demonstrates that absent a formal test for Zika, health care personnel increasingly administered dengue tests on pregnant women post-alert, but these were largely uninformative. The increase in negative/inconclusive results captures a combination of 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.

We find no post-alert impact in the frequency of counseling on contraceptives offered by health personnel, despite the fact that part of the alert related to recommending health authorities strengthened pre-pregnancy counseling to women wanting to get pregnant. This suggests the post-alert fall in pregnancy rates is driven largely by household decisions, rather than them being further influenced by the advice of health personnel.

Taken together, the results provide a rich picture of household and health care personnel responses to a new and rapidly evolving epidemic. The analysis provides policy relevant implications in terms of understanding whether and for how long households respond to public health alerts, which households drive these responses (that is useful for the optimal targeting of information), implications for child outcomes, and simultaneous margins of response of health care personnel. The results imply that disseminating information about Zika is less effective among those already pregnant and at risk. For those yet to conceive, there are great responses to the alert, with the primary welfare costs to these households being disease avoidance, as they move away from desired fertility paths or abort pregnancies, or taking offsetting precautions to mitigate the risk of mosquito bites and hence Zika infection during pregnancy.

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

A long-standing economics literature studies information as an input into the production of health [Viscusi 1990, Cawley and Ruhm 2012]. Given many instances where cost-effective actions to prevent infectious disease, that do not require individual diagnosis, still seem to have limited uptake (such as mosquito nets, vaccinations, chlorine treatment of drinking water, and deworming), a broad conclusion has been that the mere provision of information might not matter for health when other forces are at play such as externalities, credit constraints, present bias and limited attention [Kremer and Glennerster 2012] or the credibility of information [Bennett *et al.* 2018].

This micro focused literature differs from the emerging body of work on the economics of epidemics, that often represent aggregate health shocks that spread rapidly and have many dimensions of uncertainty associated with them. Economists have built on epidemiological models of disease diffusion, that standard being the Standard Inflammatory Response (SIR) model dating back to Kermack and McKendrick [1927]. The key insight has been that endogenous preventative behaviors in response to viral outbreaks impact the spread of outbreaks, and hence the optimality of various policy responses [Philipson and Posner 1993, Ahituv *et al.* 1996, Geoffard and Philipson 1996, Kremer 1996, Lakdawalla *et al.* 2006, Chan *et al.* 2016]. Such models often suggest prevalence responses *are* triggered when information on the incidence of a (contagious) disease crosses a high threshold [Philipson 2000].[4]

A nascent microeconometric literature has begun to study individual behaviors during epidemics [Bennett *et al.* 2015, Aguero and Beleche 2017, Bandiera *et al.* 2018]. Evidence remains scarce on the Zika epidemic itself, and is mostly limited to using household survey or qualitative data [Diniz *et al.* 2017, Marteleto *et al.* 2017, Quintena-Domeque *et al.* 2017] or descriptive country-level studies in public health [Aiken *et al.* 2016, Castro *et al.* 2018].[5] A common thread

---

[4] Philipson [2000] develops a model of individual behavior in the case of contagious diseases. He shows there is a threshold prevalence below which individuals engage in transmissive behavior and above which they engage in protection. Intuitively, this reservation prevalence rises with the instantaneous cost of protection and the discount rate, and falls with the cost of infection and the probability of transmission conditional on exposure. This has found empirical support in studies in the US, documenting smokers are more likely to quit when they experience more severe health shocks [Sloan *et al.* 2003, Margolis *et al.* 2014].

[5] 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.* [2017] surveyed $11,000$ women aged 15-49 in the NorthEast between March and June 2016, so well into the epidemic (with a 87% response rate). More educated women were less likely to report having Zika, more likely to report avoiding pregnancy in the last year, more likely to be aware of the association between Zika and microcephaly, and to be taking preventive actions (e.g. wearing light colored clothing, using repellents). In public health, Aiken *et al.* [2016] compare actual and expected abortion requests by country after the PAHO alert regarding ZIKV (find that the

in the economics literature is that in epidemics with high degree of human-to-human contagion (such as SARS, H1N1 or Ebola), the fear of contagion can cause individuals to avoid health care services altogether. Such prevalence responses can significantly worsen outbreaks. As we document, such avoidance behaviors are less likely to occur for Zika because the dominant transmission channel is via mosquitoes, not contagion from others.[6] Other papers has studied the effectiveness of non-information based policy responses to outbreaks such as quarantines and transportation network closures [Adda 2016]. Our work builds on this growing literature by using multiple administrative data sets to simultaneously examine the dynamic responses of individuals and health sector workers to a public health alert in the midst of an epidemic.

The paper is organized as follows. Section 2 discusses the background to Zika, the timeline and policy responses during the 2015 epidemic in Brazil. Section 3 describes the administrative records used, provides descriptives on the evolution of the epidemic, and our empirical method. Section 4 presents our results on how household behavior responds to the epidemic, sequenced chronologically through pregnancy from conception, behavior during pregnancy, and birth outcomes. Section 5 examines supply side responses of the health sector during the epidemic, in terms of hospital functioning and changes in the behavior of health care personnel. Section 6 concludes with implications for the study of future viral epidemics, and policy responses to them. The Appendix details further our data sources.

2 Zika

2.1 Background

The Zika virus (ZIKV) is a flavivirus carried by the *Aedes Aegypti* mosquito. This is familiar to Brazilians because it is the usual carrier (primary vector) for other viruses including malaria, yellow fever, dengue and chikungunya. Such familiarity no doubt affected the way in which Brazilians initially understood and responded to the virus during the first half of 2015. Prior to the Brazilian epidemic, the known symptoms of ZIKV were a mild fever, skin rash, conjunctivitis,

---

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.

[6] Bennett *et al.* [2015] study such avoidance behaviors during the 2003 SARS crisis in Taiwan. They show that outpatient visits fell by 30% in a few weeks, their main focus being to analyze how social interactions drove this response. Linking back to Philipson [2000], this suggests the social learning channel can be one reason why individuals respond strongly to novel risks. Aguero and Beleche [2017] study the 2009 H1N1 flu outbreak in Mexico, showing the epidemic nudged health behavior leading to longer lasting improvements in health. As in Bennett *et al.* [2015] they also find evidence of individuals avoiding hospital altogether due to the H1N1 pandemic. Bandiera *et al.* [2018] evaluate a women's empowerment intervention using an RCT during the 2014-6 Ebola epidemic in Sierra Leone. They document how the provision of protective spaces to women and forms of human capital provision can help insure against the aggregate health shock.

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].[7]

The new transmission mechanism identified during the 2015 Brazilian epidemic was *amniotic fluid*: so that pregnant women could transmit the virus to their fetuses [Brito 2015, Brasil *et al.* 2016]. This represents the first even known association between a flavivirus and a congenital disease. The most prominent congenital disease recognized during the epidemic was microcephaly, defined as a head circumference of two standard deviations below the mean for age and sex, or about less than the second percentile [WHO 2014]. Medical understanding of other congenital malformations related to Zika has evolved since the Brazilian epidemic. For example, it is now better established that ZIKV infection can result in a congenital malformations including those relating to brain, eye and hearing anomalies [Rice *et al.* 2018]. We use ICD-10 codes in administrative data on birth outcomes to analyze the incidence of microcephaly and other congenital malformations over the course of the epidemic to shed light on this.[8]

ZIKV infection at *any point* during pregnancy can impact fetal development. Cauchemez *et al.* [2016] report the risk of microcephaly is 1% if ZIKV infection occurs during the first trimester of pregnancy. This is low compared to other viral infections associated with birth defects (e.g. it is 13% for cytomegalovirus, and 38-100% for congenital rubella syndrome). However, ZIKV is different because the incidence in the population is very high during epidemics. For example, ZIKV infection rates were estimated to be 66% in the 2013/14 outbreak in French Polynesia. Hence although ZIKV is associated with low fetal risk, it remains a major public health issue and can cause large abrupt changes in fertility related behaviors.

There is currently no vaccine or treatment for ZIKV [Marston *et al.* 2016, Thomas *et al.* 2016]. The only way to guarantee against ZIKV-related birth defects is to avoid becoming pregnant, or to terminate a pregnancy. We study both margins of response.

---

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

[8] The last time an infectious pathogen (rubella virus) caused an epidemic of congenital defects was more than 50 years ago. No flavovirus has ever been shown to cause birth defects in humans, and no reports of adverse pregnancy or birth outcomes were noted during previous outbreaks of ZIKV in Polynesia. Two cases of perinatal transmission, occurring around the time of delivery and causing mild disease in newborns had previously been described [Oliveira Melo *et al.* 2016]. Among flaviviruses, there have only been isolated reports linking West Nile encephalitus virus to fetal brain damage [Oliveira Melo *et al.* 2016]. On establishing a causal link between ZIKV and congenital defects, Rasmussen *et al.* [2016] suggest while there is no single piece of definitive evidence establishing a causal link, they build an evidence base using (Shephard's) seven criteria. This includes that in Brazil, ZIKV was found in the amniotic fluid of two fetuses that were found to have microcephaly, consistent with intrauterine transmission of the virus [Mlakar *et al.* 2016].

2.2 Timeline

In March 2015, the WHO received notification from the Brazilian government regarding an illness transmitted by the *Aedes Aegypti* mosquito, but not detected by standard tests. By April 2015, the first case of ZIKV in continental America was confirmed. On October 16th the WHO issued a communique stating that discussions with Brazilian public health authorities had confirmed the autochthonous transmission of ZIKV in North East of the country. The communique emphasized using surveillance to determine if ZIKV had spread to other areas, and to monitor for neurological and autoimmune complications. There was no mention of threats to those *in utero*.[9]

Hence until early November, the common perception among the public and health care personnel was that Zika was a 'dengue-like' infection, and harmless to newborns. The period from May to October 2015 thus marks the pre-alert period for our empirical analysis.[10]

By late October, concerns had arisen in the North East about an increase in microcephaly cases: this was communicated by the Secretary of Health from Pernambuco to the Federal government on the 22nd October, and the WHO were notified the day after.[11] On November 11th, the Brazilian government issued a widespread and official alert emphasizing an upsurge in microcephaly in the North East, explicitly acknowledging this region as the epicenter of the epidemic, with the state of Pernambuco mentioned. This was the first time a potential connection between ZIKV and microcephaly was made. The report received major media coverage: the *Jornal Nacional* TV news network, that reaches 110 million individuals, broadcast the alert nationwide on the same day. November 2015 marks the start of the post-alert period for our analysis. Our core results document the causal impact of the alert on behaviors of households and health care personnel.

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.[12]

---

[9] The origins of the ZIKV virus in Brazil are not thought to be the 2014 World Cup 2014, as no countries from French Polynesia were in attendance, where earlier ZIKV outbreaks had occurred in 2013/14. Rather the Va'a World Sprint Championship canoe race, held in Rio in August 2014, that included athletes from French Polynesia, New Caledonia, the Cook Islands and Easter Island – all countries with a high incidence of ZIKV at the time – participated [Triunfol 2016].

[10] This is exemplified by the following quote from the Brazilian Health Ministry, made on the 14th May 2015: *"[the] Zika virus does not worry us. It represents a benign disease...It requires very little use of hospitals and medical services..All our concern now focuses on dengue because it kills." (Source: http://g1.globo.com/bemestar/noticia/2015/05/ministerio-da-saude-confirma-16-casos-de-zika-virus-no-brasil.html).*

[11] Details here: http://portalarquivos2.saude.gov.br/images/pdf/2015/novembro/19/Microcefalia-bol-final.pdf

[12] Through November, 130,000 Brazilian households undertook screening, and 220,000 soldiers were sent to patrol

Brazilian health authorities recommended pregnant women take precautions to avoid mosquito bites, and to use contraceptive methods to postpone or delay pregnancies. Health authorities recommended increasing access to contraceptives in the public health system, and to strengthen counseling to inform women who wanted to get pregnant about cases of microcephaly in the country. Our records allow us to check for whether such behavioral responses occurred among hospital personnel.

ZIKV spread rapidly across countries. A WHO communique on December 1st stated that nine WHO member states had confirmed ZIKV circulation, and there had been a 20-fold increase in reported cases of microcephaly in Brazil. On December 15th the Brazilian Ministry of Health confirmed 134 cases of microcephaly believed to be associated with ZIKV infection. In January 2016 there was the first recorded newborn with microcephaly in the US, and on February 1st 2016, the WHO launched an alert stating microcephaly was an international concern.

Brazil was the most affected country, with more cases than the rest of Latin America combined. Estimates suggest between $440,000$ and 1.3 million cases of ZIKV infection were reported through to December 2015 (among all individuals, irrespective of gender or whether pregnant) [Mlakar *et al.* 2016]. The high incidence of microcephaly was not the only peculiarity of ZIKV in Brazil: most infected women were aged around 30, and among mothers with microcephaly babies born between August and October 2015 in Pernambuco, *all* were from low SES backgrounds [Triunfol 2016]. The scale of the administrative records we exploit allow us to precisely examine heterogenous responses to the alert.

3 Data, Descriptives and Empirical Method

3.1 Administrative Records

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

The analysis of pregnancy and birth outcomes is based on live birth records (*SINASC*), that cover all live births in hospitals or homes. There were 12 million live births from January 2013 to December 2017. *SINASC* records the exact date of birth, location of birth (city and hospital), city of residence of mother, demographic characteristics of mothers, and father's age (although

---

300 cities in the North East to combat mosquito nests and advise households on the risk of stagnant water close to homes. $71,000$ soldiers were sent to Rio because of the Olympic Games being hosted there in 2016.

this is often missing). The data also records the estimated date of last menstruation, based on medical information obtained from doctors using a physical examination or other method. From this we construct an estimated date of pregnancy/conception. Birth outcomes recorded include delivery method, birth weight, APGAR scores, gender, twin births, and the number of prenatal visits. Finally, *SINASC* contains ICD-10 codes for any congenital malformation that we use to measure the incidence of microcephaly among newborns.[13]

Our working sample of birth records covers women aged 12 to 49 with no missing data on estimated pregnancy dates: we thus use $11,769,217$ birth records from January 2013 to December 2017, so covering conception dates from March 2012 to February 2017. This gives an approximate baseline mean of $250,000$ pregnancies per month, that is useful to bear in mind when documenting the magnitude of responses to the public health alert below.

As *SINASC* does not contain unique identifiers for women, we cannot link across pregnancies. We thus aggregate the data to the city-month level (cm), where we have $267,120 = (5565$ cities $\times$ 48 months) city-month observations. We define a city-month pregnancy $\text{rate}_{cm} = 1000 \times (\frac{\text{Number of pregnancies}_{cm}}{\text{Number of women}_{c,2012}})$. 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. We later also define pregnancy rates within subgroups to examine heterogenous responses to the epidemic alert across women.

To examine behavioral responses during pregnancy we merge inpatient and outpatient administrative records (*SIH* and *SIA*). These data covers all public hospitals and a subset of private hospitals that work with the National Health Service, covering more than 70% of hospitalizations. These record the date of admission, hospital of admission and city of residence of the mother. ICD-10 codes are provided for primary and secondary reasons for admission (where the treating doctor determines the diagnosis). Unique codes are provided for each medical procedure undertaken, with separate codes for primary and secondary medical procedures.

---

[13] When the estimated conception date was missing, we recovered it using information on the estimated pregnancy length. On the demographic characteristics of mothers, race categories are white and non-white. Education categories are basic, high school and diploma or more (that we use to proxy SES status). Marital status is single or married. APGAR scores are provided after one and five minutes: these measure the physical condition of newborns, obtained by adding points for heart rate, respiratory effort, muscle tone, response to stimulation, and skin coloration (the highest score is 10). These codes for thus follow the International Statistical Classification of Diseases and Related Health Problems 10th Revision, or ICD-10, created by the World Health Organization. ICD-10 codes do not change during the sample period. However, the definition used by the Brazilian government to diagnose microcephaly changed twice post-alert. The first time was on 4th December 2015 when the Ministry of Health redefined microcephaly as births with cephalic perimeter of 32 cm or lower (prior to this it was officially defined as 33 cm). The second change occurred on the 18th November 2016 when the criteria became 30.5cm 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 of the Brazilian government, 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

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

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

Our working sample is constructed from over 400 million inpatient-outpatient records from January 2013 to June 2017. As with the *SINASC* records, we aggregate the data to the city-month level (cm), where we have $300,510 = (5565 \text{ cities} \times 54 \text{ months})$ city-month observations.

We examine supply side responses to the epidemic in terms of post-alert changes in behavior among health care personnel, be they physicians, nurses or other workers that mothers come into contact with. We do so using two administrative data sources: (i) the inpatient-outpatient records that record procedures carried out on patients, as described above; (ii) an additional administrative database of notifiable diseases (*SINAN*), that covers all cases of dengue and dengue-related procedures conducted, and runs from January 2013 to December 2017.

3.2 Descriptives

3.2.1 Microcephaly and Dengue

The clearest marker of the severity of the epidemic over time is the incidence of microcephaly. Figure 1A shows the time series of microcephaly cases among newborns, by region, as reported in administrative birth records. Pre-epidemic, the number of cases per quarter 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): recall that in March 2015, the WHO first received notification from the Brazilian government regarding an illness transmitted by the *Aedes Aegypti* mosquito, but not detected by standard tests. The incidence of microcephaly peaks around December 2015 and then diminishes steadily by the end of 2016, but the series does not converge to pre-epidemic levels in most regions. Over the pre-alert period from May to October 2015, when ZIKV was known to exist in Brazil, but thought to have dengue-like symptoms, there were 395 cases of microcephaly in total. In the post-alert period, from November 2015 to April 2016 there were a further 2522 cases throughout Brazil.

The North East was clearly the mostly affected region: at the peak of crisis, it had almost 10 times the number of microcephaly cases as the next most affected region (the South East). Figure 1B shows the spatial variation in microcephaly. While this again highlights the North East as the most affected region, it also shows the considerable variation in incidence within regions. We exploit this cross-city variation in our empirical design.[14]

As highlighted in Figure A1, these temporal and spatial patterns are very different to those for dengue, that is a long-standing (urban) disease also carried by the *Aedes Aegypti* mosquito.[15]

3.2.2 Public Awareness

While the public health alert was immediately broadcast on TV media, full public awareness of the epidemic might have taken time to rise. Figure 2A shows media coverage of Zika in two major newspapers: *O Globo* and *Folha de São Paulo*, as reported in Ribiero *et al.* [2018]. There is a large increase in overall media coverage post-alert, from December 2015 [16]. They argue that framing of the epidemic made Zika a problem specifically for women; women (especially pregnant women) became the main target audience, where they "should receive orientation about how to have safe sex," [*O Globo*, 9 March 2016], to avoid microcephaly. Women were this framed as both victims of Zika, but also as those responsible for taking decisions on pregnancy.

Figure 2B shows the time series of *Google* searches for Zika, microcephaly (in Portuguese) or repellent (where the y-axis is a *Google*-provided measure of search intensity). This shows there was some public awareness of Zika and microcephaly pre-alert, spikes in awareness post-alert, with the spatial pattern of searches being more widespread (as shown in Panel C), and not concentrated

---

[14] 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].

[15] There are two obvious differences between the incidence of dengue and ZIKV. First, the prevalence of dengue increases around the rainy season, while the ZIKV outbreak occurred over summer. Panel A of Figure A1 confirms this using administrative records on the number of dengue cases by quarter. Second, dengue is concentrated in the South East and Centre West (as shown in Panel B of Figure A1), while Zika was concentrated in the North East. However, pre-alert, many individuals might have thought the new virus to be dengue-like. Panel C of Figure A1 shows the time series in *Google* searches for 'dengue' in Brazil (where the y-axis is a *Google*-provided measure of search intensity), and this follows the seasonal variation in actual dengue cases shown in Panel A. Panel D confirms that more *Google* searches are typically made in the South East where dengue is more prevalent.

[16] Ribiero *et al.* [2018] analyze 186 articles published between December 2015 and May 2016. This reveals a dominant 'war' frame of articles related to Zika, that are underpinned by two sub-frames: one focused on eradicating mosquitoes, and one focused on controlling microcephaly, but placing the burden of prevention on women. 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.

either in the North East (where the majority of microcephaly cases occurred) or in the South East (where dengue was most prevalent).

All of this is consistent with small-scale qualitative studies conducted during the crisis, such as Marteleto *et al.* [2017] and Quintena-Domeque *et al.* [2017] that suggested women expressed a desire to avoid pregnancy, and that the main reason for doing so was to avoid the possibility of becoming infected during pregnancy and transmitting the virus to the developing fetus.

3.2.3 Doctor Awareness

We use the national system of notifiable diseases (*SINAN*) to shed light on doctors' awareness of Zika. This database details individual doctor-patient meetings in all hospitals across the country relating to patients reporting symptoms of dengue. The focus on dengue follows from its high prevalence in Brazil. This sample covers meetings from January 2013 through to December 2017, although the specific details on doctor's notes are only available from January 2014 until January 2016 (so just two months post-alert), covering 3.2 million patient samples.

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

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

Finally, Panel C shows that among patients reporting dengue-like symptoms, there was increased attention to pregnant women pre-alert (that is noticeably higher compared to a year earlier). This increase occurs *before* the formal alert was issued in November 2015. It suggests that had such administrative data been available and analyzed in real time, the link between Zika and pregnancy might have been noted some months earlier.

3.3 Empirical Design

Our sample of birth records cover pregnancies conceived between May 2013 and April 2016. We divide the epidemic period in two: (i) the pre-alert period between May and October 2015, when it was known that ZIKV was in Brazil, but its symptoms were thought to be dengue-like and so with little consequence for those *in utero*; (ii) following the official alert on November 11th 2015, the post-alert period covers November 2015 through to April 2016, when the association between ZIKV and congenital disease became known. For each six month period we have corresponding control periods from the two earlier years of administrative records that we exploit to assess the validity of the common trends assumption. We estimate the following difference-in-difference specification for outcome y in city-of-residence c in month m in period t:

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

where y_{cmt} corresponds to the pregnancy 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 [Lam and Miron 1996]. 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.[17] ε_{cmt} is an error term clustered by state, to allow for contemporaneous spatially correlated shocks to pregnancy rates. To recover impacts on a representative woman, observations are weighted by the 2012 population share of women aged 12-49 in city c.

β_1 captures the difference in pregnancy rates from May to October 2015 and corresponding months in earlier years: this estimates the impact of Zika being known to exist but thought to be dengue-like. For example it might capture any behavioral response driven by a desire to avoid Zika, say through reduced frequency of sexual intercourse. β_2 captures the difference in pregnancy rates from November 2015 to April 2016 and corresponding months in earlier years: this estimates the impact of Zika being present but also known to relate to congenital malformations such as microcephaly. The key difference-in-difference is $\beta_2 - \beta_1$, captures the pure impact on outcome y_{cmt} of the informational alert linking ZIKV to microcephaly. This is our chief parameter of interest.

The main identifying assumption is that there would have been the same trend in pregnancy rates in the pre- and post alert periods in the Zika epidemic period, in the counterfactual of no

---

[17] 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. We consider as weights the inverse of the distance between the city and the station.

epidemic. In support of this, we show descriptive evidence on how pregnancy rates were changing over periods in pre-epidemic years, and also present a battery of robustness checks allowing for state or city specific time trends into the epidemic period.

Pregnancies are the first outcome we consider and they represent an important adjustment margin as individuals decide to move away from their unconstrained fertility path. This can have important consequences for women's labor supply, the welfare of other household members, and their ability to complete desired levels of total fertility.

Panel A of Table 1 presents descriptive evidence on pregnancies, by time period. We see that: (i) in the control pre-epidemic years, pregnancy 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, pregnancy rates are no different in 2015 than earlier years (4.24 vs 4.19); (iii) pregnancies rates fall further during the epidemic post-alert than similar months in earlier years (3.57 vs 3.91); (iv) the difference-in-difference in pregnancy rates is negative and significant ($-.296$, $p = .000$), corresponding to an 8% fall in pregnancy rates relative to November-April months pre-epidemic.

4 Household Responses to the Epidemic

4.1 Pregnancy Rates

Table 2 shows how pregnancy rates respond to the public health alert linking ZIKV and microcephaly. The foot of each Column reports the key difference-in-difference (DD) with its associated 95% confidence interval. To benchmark magnitudes, we show the baseline mean of the outcome variable (the May to October period in pre-epidemic years), and the percentage impact the DD estimate corresponds to in parentheses.

Columns 1 and 2 control for city and month fixed effects, while Column 3 controls for both simultaneously. Column 4 estimates (1) in full and represents our baseline estimate. We find that: (i) $\widehat{\beta}_1$ is not statistically different from zero, so that pre-alert, the known presence of Zika in itself does not change pregnancy rates relative to earlier years (this suggests there was no behavioral response to avoid Zika infection *per se*, through reduced frequency of sexual intercourse all else equal); (ii) $\widehat{\beta}_2 = -.319$ and this is statistically different from zero ($p = .000$), so that post-alert, there is large reduction in pregnancy rates; (iii) the DD is $\widehat{\beta}_2 - \widehat{\beta}_1 = -.306$, that is statistically different from zero ($p = .000$). This isolates the causal change in pregnancy rates due to the public health alert highlighting the link between ZIKV and microcephaly.

The magnitude of household responses corresponds to a 7.21% reduction in pregnancy rates, 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 pregnancy rates [Lam and Miron 1996]. 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 fluctuation in pregnancy rates across months of the year.

This reduction in pregnancy rates is derived from birth records: hence it corresponds to households deciding to delay pregnancy. We later document changes in behavior during pregnancies, including the increased use of abortions that further reduces birth cohort sizes. The administrative records cover all births: those in hospital and those at home. Hence the fall in pregnancy rates is not driven by individuals avoiding hospitals post-alert. Such prevalence responses have been documented in other epidemics as individual fear contagion at hospitals or lose trust in the health care system [Bennett *et al.* 2015, Evans *et al.* 2015,] but are not a valid explanation for responses in the Zika epidemic.[18]

To check for this, in Table A1 we use the linked inpatient-outpatient records to estimate how hospital admissions change over the epidemic (as constructed from over one billion patient admission episodes and then aggregated to the city-period level). This shows no change in admission rates among the general population (Column 1), and this remains the case when we allow for state specific time trends (Column 2). Narrowing in on hospital admission rates for pregnant women, we see that the fall in admissions rates is 6.91%, that matches closely the estimated fall in conception rates (Column 3) and this remains the case when we allow for state specific time trends (Column 4). Taken together these results both confirm households do not avoid using hospitals during the epidemic, and the finding on the admissions rate for pregnant women helps validate the baseline results on pregnancy rates derived from administrative birth records.

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

---

[18] Evans *et al.* [2015] document how during the 2014-6 Ebola epidemic in West Africa, deaths were disproportionately concentrated among health personnel. For example, by May 2015, while .06% of the population had died from Ebola, 6.85% of health care workers had died from Ebola. This led to a rapid loss of trust and usage of hospitals. Bennett *et al.* [2015] show that during the 2003 SARS epidemic in Taiwan outpatient visits fell by more than 30 percent in a few weeks, in response to public information and multiplier effects of social interactions.

selection of mothers that choose to conceive despite the risks highlighted in the alert.[19]

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

Finally, Column 8 allows the post-alert impacts to vary by region, where the South is the reference category. There are significant reductions in pregnancy 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 descriptive time series on microcephaly shown in Figure 1A.[20]

Table A2 presents a battery of further checks. For ease of comparison, Column 1 repeats the baseline specification from Column 4 in Table 2. The remaining Columns show this result to be robust to: (i) dropping month fixed effects and then controlling for $PRE\text{-}ALERT_m$ and $POST\text{-}ALERT_m$ directly (Column 2); (ii) not weighting observations: suggesting the results are not driven by large cities (Column 3); (iii) dropping smaller cities that ever had zero pregnancies in a month over the sample: suggesting the findings are not driven by small cities (Column 4); (iv) including additional birth records data from 2012 (that were originally dropped because of pregnancy dates being less reliably recorded in that year) (Column 5); (v) using an alternative numerator to calculate pregnancy rates that accounts for women currently pregnant for observation t in city c and so not at risk of conceiving (Column 6).[21]

A final concern is that the epidemic caused women to migrate to different cities to give birth,

---

[19] Throughout out analysis we do not therefore condition on mother characteristics because these are endogenously determined post-alert.

[20] The magnitude of the response in the North East is very similar to that implied by survey evidence collected from women survey in the North East during the outbreak. For example, among the 11,000 women aged 15-49 surveyed in that region between March and June 2016, Quintena-Domeque *et al.* [2017] find that 51% of them report having used contraceptives (or abstinence) to delay or avoid getting pregnant in the last 12 months. Among this 51%, 18% reported this behavior to be motivated by Zika, corresponding to a $.51 \times .18 = 9\%$ response overall. Our DD design implies a 10% reduction in pregnancy rates in that region.

[21] 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, $t-1, ...t-8$.

changing the underlying composition of those giving birth in city c. We check for this in Column 7 of Table A2 where the outcome is the share of women giving birth in the city-period whose city of residence and city of birth differ. We see the DD on this is zero and precisely estimated. The evidence strongly suggests the alert did not cause women to migrate across cities to give birth. However, we probe this further by focusing in on those cities where abortions or ultrasound are offered by hospitals. Neither service is universally offered in Brazil: 31% of cities provide abortions and ultrasound, 45% provide neither, 15% provide only abortions, and 9% offer only ultrasound. The set of cities with the technology and infrastructure to offer these services are the largest ones: so around 80% of all women have access to both services, and this set of cities does not change over the epidemic. Columns 8 and 9 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. We further examine the role these services play below when studying behavioral responses during pregnancy to the public health alert.[22]

The results on household responses to the health alert have important implications for the wider literature in health. First, it is often found that individuals are willing to spend more on treatment than prevention, holding cost effectiveness constant [Kremer and Glennerster 2012]. Often the preventative behaviors in question are those that would benefit children (such as vaccination), suggesting household decision making places low weight on child health, or that present biases or limited attention prevent such actions being taken. This is not the case for the public health warning during the Zika epidemic: the sizeable reduction in pregnancy rates implies many households are willing to take action to avoid exposure to the risk of the virus altogether, a risk that predominantly intergenerationally transmits to unborn children. As in Philipson [2000], we thus interpret the epidemic as a random 'tax' on behavior which risks exposure, so distorting individuals' choices by inducing them to forego that otherwise valuable activity. This is the first order welfare cost of the epidemic, that impacts far more individuals than those that actually suffer congenital malformations through Zika – recall that Cauchemez *et al.* [2016] report the risk of microcephaly is 1% if ZIKV infection occurs during the first trimester of pregnancy.

4.2 Dynamic Responses

Responses to the alert might not be immediate if it takes time for the information to spread, or for individuals to become convinced of the risk (recall from Figure 2A, it was only in early 2016 that there was widespread media reporting of Zika). We consider two approaches to understanding

---

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

dynamic responses. First, the birth records actually provide an estimated *week* of pregnancy. To examine short run dynamic responses to the alert we therefore show weekly pregnancy rates in the period around the alert and compare those to pregnancy rates from the same week in the year before. This descriptive evidence is in Panel A of Figure 4, and although the weekly estimates are noisy, we see: (i) in the weeks prior to the alert, weekly pregnancy rates were very similar in the year of the ZIKV epidemic and the year before (so no evidence of pre-trends); (ii) immediately after the alert – within a week – a divergence in pregnancy 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 to dynamic responses extends the monthly sample into the post-alert period to pregnancies up to February 2017 and estimates the following specification:

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

where $Alerttime_t$ is the number of months since the official alert publicly linking Zika and microcephaly. $Alerttime_t$ is defined to be zero in November 2015 and we allow it to run from -6 to $+15$ (where negative values thus shed light on the dynamics of β_1 from (1)). We define pregnancy rates in logs so that we can more easily compare percentage impacts across time.

Panel B shows the sequence of $\widehat{\beta}_{3t}$'s from (2). There is again no evidence of differential trends pre-alert. There are however significant falls in pregnancy rates for 9 months post-alert. Pregnancy rates fall the month before the official alert: this effect is driven by households in the South East, where dengue is most prevalent and households have the best access to contraception. Focusing on dynamic responses in the North East (where Zika was most prevalent), the sequence of $\widehat{\beta}_{3t}$'s is shown in Panel C: here we see no change in pregnancy rates pre-alert, the trough occurs some three months post-alert, suggesting it takes some time for the information from the alert to fully disseminate. Pregnancy rates return to trend 9 months post-alert. Pregnancy rates thus return to trend while microcephaly cases remain above their pre-epidemic levels, as shown in Figure 1.

These falls in pregnancy rates reflect women moving away from their unconstrained fertility path, and so might have consequences for their labor supply, the welfare of other household members, and longer term ability to complete desired levels of total fertility. These dynamic responses are also shorter-lived than suggested by qualitative evidence collected from mothers during the epidemic.[23]

---

[23] 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 2 or 3 years, to more abstract answers, such as, "when they find a cure," "when they create a vaccine," or "until doctors learn more about the epidemic and the mechanisms by which it affects the baby."

4.3 Heterogeneous Responses

The near universal coverage of the administrative birth records allow us to precisely establish heterogenous responses to the alert across subgroups of mothers whose pregnancy went to term. Heterogeneous responses can be driven by variation in information, risks and costs of delaying pregnancy across women. For example, higher SES women might be better informed of the risks linking Zika and microcephaly, or might be better informed of and be able to take the kinds of preventative action to avoid mosquito bites (such as using repellents or window screens etc.). On the other hand, in Brazil where access to family planning remains constrained, higher SES women might have access to more reliable forms of contraception, and safer forms of abortion. Hence they would be more able to continue along their pre-epidemic planned fertility path.[24]

For each subgroup, we estimate a specification analogous to (1), but define pregnancy rates in logs to directly compare percentage impacts across subgroups. Figure 5 plots $\widehat{\beta}_2 - \widehat{\beta}_1$ for each subgroup, and its associated 90% confidence interval. The results in Figure 5 show that: (i) there are few significant differences in response based on race (white versus non-white) or marital status (single versus married); (ii) there is a strong gradient between pregnancy rate responses and education: mothers with low education (up to 7 years) respond less than mothers with high-school (8 to 11 years), who in turn respond less than mothers with a diploma (12 or more years); (iii) there is a U-shaped gradient between pregnancy rate responses and age: mothers in their 30s respond most to the alert: the lack of response among older women can reflect the cost of delaying pregnancy being higher for them if it leads to an inability to conceive later.[25]

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

The documented heterogeneity in responses fits the narrative that higher SES women were better informed of the risks, or face lower costs of altering their fertility timing, and so delayed

---

[24] Going to a clinic each month for contraception is time consuming, and to pay the subsidized price of contraceptives, women need to present a valid prescription and a picture ID, requirements that are not necessary when purchasing at full price. Both costs are higher for low SES women. In contrast, high SES women are more likely to visit private clinics or buy contraceptives at pharmacies without a prescription. In line with this, Marteleto *et al.* [2017] find that low SES women report fewer choices of contraception than high SES women. Low SES women frequently reported using the pill, injections, or condoms, all of which are available at public clinics, while high SES women reported going to private clinics and being able to afford IUDs and vaginal rings. Low SES women also reported feeling stigmatized when they went to public clinics for contraceptives, often because of a violation of privacy by health clinic personnel.

[25] There is a vast body of work linking health and education, that generally finds positive impacts of education on health. This is the case in both high- and low-income settings: Cawley and Ruhm [2012], and Kremer and Glennerster [2012] provide excellent overviews of the evidence from each setting respectively.

pregnancy more during the post-alert period.[26] An implication is that the cohort of children that are conceived post-alert are slightly negatively selected, in that they are more likely to be born to younger and lower SES mothers relative to the pre-alert period and relative to the counterfactual no epidemic scenario. We thus interpret later outcomes for this cohort as being partly driven by the selected sample of lower SES mothers that choose to conceive despite the risks highlighted in the official alert.

We provide one additional piece of descriptive evidence to tease apart what might drive heterogenous responses: using ICD-10 codes at birth from the birth records, we can calculate relative risk ratios for microcephaly for various subgroups of women (namely the share of newborns with microcephaly with mothers in group g, divided by the share of all mothers in group g). We do so for the same subgroups as considered in the analysis of heterogeneous responses in pregnancy rates in Figure 5, and do so separately for the pre- and post-alert periods.

Figure 6 shows the results: this emphasizes that risk ratios differ from one across subgroups. Focusing on pre-alert risk ratios to begin with, we see that white mothers face lower risk than non-white mothers, married women face lower risk than singles, risk falls with education levels and age. Of course these differences reflect differences in exposure to mosquitoes as well as preventative behaviors against bites. However the results suggest that those older and higher SES mothers that responded most to the alert, faced lower *ex ante* risk of their newborn being born with microcephaly.

Changes in relative risks pre- to post-alert are also informative of potential changes in preventative behaviors during pregnancy by subgroup. Here we see a general convergence of risk ratios across subgroups towards them all being closer to one post alert (especially so for race, age and education). This suggests that among women conceiving post-alert, all women improved preventative actions against bites during pregnancy, so shifting relative risks closer to one for all.

4.4 Behavior During Pregnancy

We next examine changes in behavior during pregnancy among women that conceived during the epidemic. To do so, we use the linked inpatient-outpatient administrative records to construct a city-month panel and estimate specifications analogous to (1). The outcomes analyzed are

---

[26] These findings are consistent with the survey evidence in Quintena-Domeque *et al.* [2017]: they report more educated mothers are more likely to follow preventive measures against Zika such as having long and light colored clothing, using mosquito repellent or insecticides, having mosquito protective screens at home or keeping windows closed, and having removed standing water where mosquitoes can breed. They are also more likely to report being aware of the association between Zika and microcephaly. Recall that in relation to the earlier descriptive evidence on media coverage of the outbreak, Ribiero *et al.* [2018] note that the Zika outbreak 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.

pregnancy tests, ultrasounds, abortions and the total number of prenatal visits during pregnancies (where the last outcome is measured from birth records, for those pregnancies that go to term). For all outcomes except prenatal visits, rates are calculated as the number of such outcomes in city c in time period t per 1000 women that conceived in the same city c in the previous three months, as predominantly it is only those women in the first trimester of pregnancy that are 'at risk' of each outcome. For prenatal visits, we calculate the average number of visits per pregnancy in the city-period, as measured at the end of the pregnancy.

Panel B of Table 1 presents descriptive evidence on these outcomes, by time period. We see little difference-in-difference in pregnancy test rates: these appear to be naturally rising over time and are always higher between November and April than between May and October. This sustained demand for pregnancy tests implies households were not avoiding hospitals during the epidemic for fear of contagion, as has been documented in other epidemics such as Ebola or H1N1 [Bennett *et al.* 2015, Aguero and Beleche 2017]. As Table A1 showed, such avoidance behaviors occur less for Zika because the dominant transmission channel is via mosquitoes, not contagion from others.

Pre-alert around a quarter of women undergo an ultrasound, and this rises significantly post-alert: the DD is 22 ($p = .000$), corresponding to a 9% rise over the November-April period in pre-epidemic years. Despite severe legal restrictions, abortion rates are high pre-epidemic: around 16% of women pregnant in the previous three months have an abortion (partly reflecting the lack of contraceptive access in this context), and this rises further post-alert: the DD is 8 ($p = .004$) corresponding to a 5% rise over the November-April period in pre-epidemic years.[27] Finally, for pregnancies going to term, the number of prenatal visits does not differ across periods. Hence, there is no change in total exposure to health services using this measure.

Table 3 presents the regression results. These make two refining adjustments over the descriptive evidence. First, for each outcome (except prenatal visits), we examine two samples: all cities (as in Panel B of Table 1), and the subset of cities reporting a strictly positive outcome in at least one time period. This second sample is relevant because not all cities provide pregnancy tests, ultrasound or abortions in hospital, although the set of hospitals providing such services does not change over the course of the epidemic.

Second, we split pre- and post-alert periods into quarters. This allows us to more precisely pin down changes in behavior among women that almost surely conceived their pregnancy in the

---

[27] There are restricted legal conditions for women seeking 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). Clearly, the administrative records suggest in practice, abortions occur far more frequently than in only these circumstances.

pre- and post-alert periods. Recall, unlike the birth records used earlier, the inpatient-outpatient records contain no details on conception date, so outcomes are measured in the time period t when the event takes place. However, assuming pregnancy tests, ultrasounds and abortions occur in the first trimester of pregnancy, then by splitting pre- and post-periods into quarters, we are almost sure that those whose outcome occurs in the second quarter of the pre-alert period (from August to October 2015) conceived in the pre-alert period, and similarly those whose outcome occurs in the second quarter of the post-alert period (from February to April 2016) almost certainly conceived in the post-alert period. Hence the difference-in-difference that best isolates the pure impact of the alert on those that conceived pre- and post-alert compares between these quarters and pre-epidemic years. This is the DD shown at the foot of each Column in Table 3.

The DD in pregnancy tests is not statistically different from zero. In contrast, the DD in ultrasound rates is positive and significant, both in all cities as well as in those cities where ultrasounds are available. The magnitudes of the effects are 35 and 39 respectively, that both correspond to 16% increases over the baseline rate of ultrasounds (these magnitudes are similar because the observations are weighted by the city population of women, and the largest cities offer ultrasound services).

The DD in abortion rates is positive and significant, both in all cities as well as in those 2193 cities providing abortions. The magnitudes of the effects are 16 and 19 respectively, that both correspond to 9% increases over the baseline. These increases occurred despite formal restrictions on its use, and much controversy over the use abortion during the epidemic.[28]

Converting this response to absolute numbers we find that it corresponds to around just under $4,000$ more abortions per month occurring post-alert, so adding around a further 20% decline in cohort sizes driven by the $18,000$ fall in monthly pregnancies documented earlier.

An alternative way to measure impacts on abortions by city-month is to use administrative records from the Mortality Information System (*SIM*). While this also covers all cities in Brazil, these records relate to the subset of fetal abortions that have gestation length of at least 20 weeks, a weight of at least 500 grams and a physical length of at least 25 centimeters. Hence the *SIM* data measures late-term abortions. Column 4 of Table 3 shows that for this measure of abortions, the key difference-in-difference is significantly greater than zero ($p = .000$). The magnitude of the effect corresponds to a 15% increase in these late term abortions. Overall, our findings suggest that there are both more abortions occurring post-alert, with a shift in the timing of abortions

---

[28] Religion plays an important role, with the church taking a conservative position. For example, as reported by *O Globo* on 5th February 2016, "*...the National Conference of Brazilian Bishops (CNBB) declared that the occurrence 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].

so more occur later in pregnancies. Some of these might well be among women that conceived pre-alert and so could only possibly abort late in their pregnancy.[29]

For ultrasounds and both measures of abortion, the DD is significantly different from zero and is driven by changes in behavior during pregnancy of those select group of mothers that conceived post-alert ($\widehat{\beta}_2 > 0$) rather than changes in behavior among (non-selected) mothers that conceived pre-alert ($\widehat{\beta}_1 = 0$). Two points are of note from this. First, this lack of behavioral response during the first trimester of pregnancy is all despite the unborn children of those that conceived pre-alert also obviously being at risk from ZIKV infection. This lack of response shows that not all at-risk households respond to public health alerts; this lack of responsiveness is more in line with the kind of limited attention or endogenous belief formation that seems to explain many health behaviors outside of epidemics [Kremer and Glennerster 2012, Dorsey *et al.* 2013]. Second, among mothers that conceive post alert, the significant increase in abortions suggests a second stage of selection into birth outcomes that we study below (beyond the first stage of selection into pregnancy as discussed above).

Finally, Column 5 shows the impact of the public health alert on the number of prenatal visits made during the entire pregnancy, among those that go to term. Unlike the earlier outcomes, the outcome is measured in birth records, so we can measure it by month of (estimated) conception. Two points are of note. First, mothers that conceive during the Zika epidemic, either pre- and post-alert, have significantly more pre-natal visits over their pregnancy than women in pre-epidemic years. Hence there is greater exposure to the health service for those mothers conceiving from May 2015 onwards when Zika was known to be present in Brazil. However, the DD shows there is a *fall* in the average number of prenatal visits for those mothers that conceive post-alert. Hence these mothers have less exposure to health professionals than mothers that conceive pre-alert. However, the magnitude of this mean impact is small (corresponding to a 1% reduction in prenatal visits).[30]

---

[29] Our estimates likely reflect a lower bound for the true abortion responses to Zika: given restrictions to access abortions, some women might perform abortions at home or illegal clinics – these would not be picked up in the *SIH* administrative inpatients data. Marteleto *et al.* [2017] starkly describe qualitative evidence from focus groups of women during the epidemic on how access to abortion varied by SES. Low SES women were more likely to know women who had suffered an unsafe abortion, while high SES women reported reliance on private doctors to perform surgical abortions or refer them to other trusted private doctors. As a result, high SES women might be able to wait longer in pregnancy to detect microcephaly or other congenital malformations.

[30] Further analysis reveals that this mean reduction is driven by a significant fall in the share of mothers with 7 or more pre-natal visits, and a significant rise in the share of mothers with 1-3 or 4-6 visits (there is no shift in the share with zero pre-natal visits).

4.5 Birth Outcomes

Birth outcomes are derived from birth records, and so can be defined for pregnancies conceived in period t, with outcomes measured as the rate per 1000 births in the city-month. Table 4 presents the results where we estimate a specification analogous to (1).

Focusing on the difference-in-difference throughout, we see that at birth, children conceived post-alert are no more likely to be delivered by Cesarean section (Column 1), and are significantly more likely to be born premature, although the percentage impact is small (1.7%) (Column 2).

Birth weight is the most widely used indicator of neonatal health and has been consistently shown to correlate with later life outcomes such as health and cognition in childhood, educational attainment, wages and longevity [Almond and Currie 2011]. In Column 3 we find that children conceived post-alert are significantly *less* likely to be low birth weight relative to those conceived pre-alert. While this result is at first puzzling it is useful to distinguish between the two cohorts driving the DD, given the earlier results on the post-alert selection into pregnancy and abortion. Among those conceived pre-alert, 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 the non-random group of children conceived post-alert (i.e. among mothers that did not delay pregnancy) and that reached full term (i.e. among mothers that did not abort), the likelihood of low birth weight also rises relative to pre-epidemic years but by not as much ($\widehat{\beta}_2 = .813$, or 1% of the baseline mean).[31]

Presumably this is because of the two stages of selection out of pregnancy and birth. We investigate this further by splitting outcomes between cities that do/do not offer abortion or ultrasound services in hospitals. Recall that neither service is universally offered in Brazil: 31% of cities provide abortions and ultrasound, 45% provide neither, 15% provide only abortions, and 9% offer only ultrasound. The set of cities with the technology and infrastructure to offer these services does not change over the epidemic. Table A3 shows that: (i) the DD in premature births is driven by cities that offer ultrasound or abortion (Panel A); (ii) the DD in low birth weights is also driven entirely by cities that offer ultrasound or abortion (Panel B).[32]

4.5.1 Microcephaly and Other Congenital Malformations

The final set of birth outcomes we examine are more Zika-specific risks: the incidence of microcephaly, and of other congenital malformations. Panel C of Table 1 presents descriptive evidence

---

[31] Birth weight is also well recognized to only be a proxy for neonatal conditions. Conti *et al.* [2018], use data from ultrasounds to show that fetal measures of development related to the fetal head, abdominal and femur size are better predictors of later outcomes than birth weight (even accounting for unobserved heterogeneity across children or mothers). Unfortunately, we do not have any such fetal indicators in our administrative records.

[32] We find that there is no impact on child gender or the incidence of twin births either in the pre- or post-alert periods, so there appears to be no selective abortion on those grounds.

on these outcomes across time periods, defined by month of conception. The pre-alert incidence of microcephaly is low: .06 per 1000 births (or close to 1 in $17,000$ births) of those conceived May to October are diagnosed with microcephaly, but there is a strong seasonal trend in its incidence; (ii) post-alert, the incidence of microcephaly among those conceived pre-alert rises by factor of 13, while for those conceived post-alert it falls by 31%. The DD is -1.00 ($p = .019$).

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

Columns 4 and 5 in Table 4 show the regression adjusted estimates. Column 4 shows a marked rise in microcephaly among children conceived pre-alert: $\widehat{\beta}_1$ shows that the incidence of microcephaly rises by .808 per 1000 births, relative to a baseline mean of .061 cases per 1000 births. This corresponds to a 1324% increase in microcephaly cases. For those select children conceived post-alert, there is *no* significant difference in rates of microcephaly relative to children born in similar months in pre-epidemic years: $\widehat{\beta}_2 = -.239$ and is not statistically different from zero. Hence overall the DD is -1.04, corresponding to a 1700% reduction in microcephaly rates among those conceived post-alert relative to those conceived pre-alert. Hence despite post-alert births being concentrated among younger and lower SES mothers (that also do not abort the pregnancy), the findings are consistent with these mothers taking offsetting precautions to mitigate the risk of Zika infection during pregnancy (as Figure 6 suggested). This represents a third dimension of prevalence-response to the epidemic (beyond delayed conception and aborting pregnancies).[33]

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

On other congenital malformations, Column 5 of Table 4 shows similar increases pre- and post-alert. However, this masks some important heterogeneity: exploiting ICD-10 codes we can estimate impacts by diagnosis at birth. Figure 7 summarizes the resulting estimates of $\widehat{\beta}_1$,$\widehat{\beta}_2$ and $\widehat{\beta}_2 - \widehat{\beta}_1$. Panels A and B are on very different y-axis scales. Panel A focuses on congenital malformations, such as microcephaly, where the estimated coefficients are large in absolute value. We see that microcephaly is the most impacted outcome for children conceived pre-alert. We also note increases in ankyloglossia (ICD Q381, tongue-tie) among those conceived over the epidemic but these are not precisely estimated. On the rarer conditions shown in Panel B, those conceived

---

[33] 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.

pre-alert are significantly more likely to be born with dextrocardia (ICD Q240, a rare condition in with the heart is on the wrong side of the chest), and those conceived post-alert are significantly more likely to be born with dolichocephalics (ICD Q67.2, an unusually long skull).

These administrative records are the best possible data source for understanding potential impacts of the Zika epidemic on a wider range of congenital malformations: they confirm some of the ongoing discussion in the medical literature on the wider impacts of ZIKV on newborns beyond microcephaly, that was the primary concern during the epidemic.[34]

4.5.2 Dynamics of Microcephaly

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

Figure 8B repeats the analysis by region: it shows the pre-alert impacts are nearly all driven by increases in microcephaly cases in the North East, with there also being significant increases in microcephaly in the South East (although the magnitude of the response is far smaller). In all other regions, robust statistically significant dynamic impacts are not found.

As with our earlier analysis of administrative data from doctor-patient meeting notes (that highlighted a potential link between Zika and pregnancy), these results suggest that had it been

---

[34] The WHO epidemiological bulletin of December 2015 discussed various congenital malformations that had been reported in French Polynesia, where Zika is prevalent. These included brain lesions, brainstem dysfunction and an absence of swallowing. By mid 2018, the medical literature had established that ZIKV infection can result in a wider range of congenital malformations including those relating to brain, eye and hearing anomalies [MMWR, August 7th, 2018]. This wider range of consequences implies the incidence of microcephaly during the epidemic likely provides a lower bound on the true rate of Zika infection.

possible to analyze administrative birth records in real time, authorities might have become aware of the spike in microcephaly months before it was actually realized.[35]

5 Supply Side Responses to the Epidemic

We next examine 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. These help us interpret whether the documented household responses might be driven by the behavior of health care personnel. We use two sources of administrative data to document these changes: (i) the national system of notifiable diseases (*SINAN*), that covers all cases of dengue in Brazil; (ii) inpatient-outpatient records that detail procedures implemented on patients (as recorded by physicians). The results are in Table 5 where all outcomes are measured in period t for each city-month.

5.1 Administering Dengue Tests

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

The result in Column 1 shows: (i) no change in the use of dengue tests among pregnant women during the pre-alert period ($\widehat{\beta}_1 = 0$) (ii) a rise in the use of dengue tests for pregnant women post-alert ($\widehat{\beta}_2 > 0$): the DD corresponds to a 249% increase over the baseline mean. To gauge the speed of response, Figure A2A shows the rate of dengue tests administered to pregnant women, by week, in a narrow window around the health alert. Although the series is noisy, there is a clear structural break in the series on the use of dengue tests for pregnant women in the week after the alert, with a rising trend thereafter. Furthermore, on dynamic behavioral changes, Figure A2B plots the dynamic DD estimates from a specification analogous to (2) for dengue test rates for pregnant women. We see that pre-alert, there was no change in the administration of these tests relative to earlier pre-epidemic years, and that post-alert there was a steady increase in their usage. This peaked some three months after the alert, and declined back to trend around eight

---

[35] 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].

months post-alert (so around the time that pregnancy rates had also returned to pre-epidemic trends, as shown in Figure 4C).

Absent a widely available test for ZIKV, there is a rationale for administering dengue tests: as Zika is still closely related to dengue, serologic samples may cross react in tests for either virus [Petersen *et al.* 2016]. However, on the outcomes of these dengue tests, Columns 2 and 3 in Table 5 show that post-alert, there are even larger percentage increases in negative dengue test results for pregnant women (878%), and in inconclusive test results (1600%). What this demonstrates is that absent a formal test for Zika, health care personnel increased the administration of dengue tests on pregnant women post-alert, but these were uninformative in many cases. The increase in negative/inconclusive results capture a combination of 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.[36]

If this inability to diagnose Zika resulted in a loss of trust in the health care providers, it did not lead to any substantive reduction in the number of individuals or pregnant women still seeking health care, as evidenced earlier.

5.2 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 get to 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 cases of Zika. 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 5 shows a large increase in diagnosed cases of Zika infection over the epidemic (both pre and post-alert), but the increase is 10 times larger post alert. The DD corresponds to a 1466% increase in Zika infection rates. Beyond these diagnosed cases, there might also be undiagnosed cases of Zika. We define these as cases where a doctor has performed tests for dengue, yellow fever and chikungunya (all diseases transmitted by *Aedes Aegypti*), but did not diagnose any of these. Here we see rises in potentially undiagnosed cases of Zika over the course of the epidemic, with the DD corresponding to a 22% increase. Reassuringly, the magnitudes of undiagnosed Zika cases are always smaller than for diagnosed cases.

To chart the dynamic incidence of Zika cases, we estimate a specification analogous to (2).

---

[36] Table A4 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.

Figure 9 shows the complete set of dynamic DD estimates. Pre-alert, there are almost no changes in the incidence of Zika diagnosis relative to pre-epidemic years: in line with the earlier result that pre-alert, health personnel were unaware of the dangers of Zika and largely reliant on using dengue tests to diagnose it. However, there is a clear rise in Zika diagnosis post-alert: this peaks 4 months after the alert, and remains significantly higher up to 7 months post-alert.

While Figure 9 shows how health care personnel diagnosed Zika infection in the second half of the epidemic, it does not tell us the true incidence of ZIKV infection during the entire epidemic. This is seen comparing Figures 8 and 9: the rise in microcephaly cases occurs almost entirely pre-alert, while diagnosed Zika cases rise post-alert. The peaks are 12 months apart, suggesting a year lag in the peak of ZIKV infection and the ability for health personnel to diagnose it.[37]

5.3 Other Margins

Column 6 of Table 5 investigates the other policy relevant dimension of personnel behavior: counseling those at risk of becoming pregnant on contraceptive use (as a rate of per 1000 women). We see no post-alert impact in counseling on contraceptives, despite the fact that part of the alert related to recommending health authorities strengthened pre-pregnancy counseling to women wanting to get pregnant. This suggests the post-alert fall in pregnancy rates is driven largely by household decisions, rather than them being further influenced by the advice of health personnel.[38]

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

We have also examined hospital functioning over the crisis using the National Register of Health

---

[37] Of course we could use the incidence of microcephaly to back out estimates of the actual incidence of Zika in the population as a whole, but this requires a large set of assumptions: (i) the risk of microcephaly is 1% if ZIKV infection occurs in first trimester of pregnancy [Cauchemez *et al.* 2016]; (ii) if ZIKV infection occurs in the last two trimesters it does not result in microcephaly; (iii) ZIKV infection equally likely in any trimester of pregnancy; (iv) pregnant women are as likely to be infected with Zika as non-pregnant individuals. Combining these assumptions with data on the share of the population that is in the first trimester of pregnancy, this would produce a estimated series for the incidence of Zika in the population. This would essentially just be a scaled-up version of Figure 8A on the time series of microcephaly.

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

Establishments (*CNES*). This records the number of rooms and beds available, by obstetric and neonatal speciality, at each hospital. It also records other hospital facilities, and the existence of hospital committees. In short, and 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 post-alert household responses documented should be driven by changes in the aggregate supply of health care services.[39]

6 Conclusions

Given the underlying forces driving the frequency and complexity of viral outbreaks, all countries need to prepare to combat such aggregate shocks. Yet most countries have low investment in disease surveillance and diagnostic laboratories, that aid early identification, response, and containment of epidemics [World Bank 2017]. This level of investment is potentially suboptimal given: (i) the low cost of preparedness relative to the economic impacts of epidemics; (ii) complementarities between epidemic preparedness and the regular functioning of health services; (iii) the limited ability of international agencies such as the WHO to immediately respond to outbreaks [Currie *et al.* 2016]. This last feature was strikingly revealed by our administrative data: given the timing of the uptick in microcephaly, ZIKV was likely present in Brazil some months before the WHO was first alerted in March 2015.

With a lack of preparedness, especially in countries with low state capacity, it is vital to understand the endogenous responses of households and health care personnel to the emergence of new and rapidly spreading epidemics. Such prevalence elasticities and disease avoidance behaviors are often the first order welfare cost of epidemics, form the key wedge between economic and epidemiological models of disease diffusion, and have implications for policy design and targeting. Such an analysis lies at the heart of this paper, in the context of the 2015 Zika epidemic in Brazil, where the primary policy response was a public health alert providing information linking ZIKV to microcephaly. The administrative data sources we exploit allow us to pinpoint the most important

---

[39] More precisely, on the number of obstetric centers and the number of neonatal centers we find the difference-in-difference in health service provision is not statistically different from zero. One dimension of health service provision that does increase post-alert is the number of hospital beds available for pregnant women (measured as a rate is per 1000 conceptions in the city in the previous eight months): the supply of beds increases by 5% post-alert relative to the pre-alert period. On the organization of hospitals, we find no changes in hospital functioning as measured by the number of committees tasked to control infections or to issue notifications on diseases. This underpins the earlier stated finding that not all cities provide pregnancy tests, ultrasound or abortions in hospital, but that the set of hospitals providing such services does not change over the course of the epidemic. These results also match a lack of supply side responses that has been documented in the other study that has examined such impacts during an epidemic. More precisely, Aguero and Beleche [2017] examine supply side impacts of the 2009 H1N1 viral epidemic in Mexico and find little impact on outcomes such oral rehydration salts administered, vaccines administered or the number hospital beds provided.

responses: for households, these are in terms of disease avoidance through avoiding pregnancy, abortions during pregnancy, and reducing risk of mosquito bites during pregnancies that go to term; for health care personnel these are in terms of the increased use of dengue tests, but not additional advice on contraceptive counseling for those seeking to become pregnant.

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

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

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

A Data Appendix

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

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

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

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

Hospital Information System (SIH) This provides inpatient data for all public hospitals and a subset of private hospitals that work with the National Health Service (SUS), and are paid to care for patients: this covers more than 70% of hospitalizations. These administrative records are updated every two months. The data is collected at the point of hospital admission for each patient. It records their city of residence and the exact date of admission. However, it does not provide any patient characteristics. Primary and secondary reasons for admission are coded using International Disease Codes (ICD-10). Unique codes are provided for each medical procedure undertaken, with separate codes for primary and secondary medical procedures. Reason for hospital discharge are also provided.

Ambulatory Information System (SIA) This provides outpatient data for all public hospitals and a subset of private hospitals that work with the National Health Service (SUS). These administrative records are updated every two months. In contrast to the inpatient records, the SIA do record patient characteristics including their age, gender, race, migrant status, city of residence and reason for leaving the hospital. They record the exact date of appointment, and when the appointment was recorded in the system. Primary and secondary reasons for admission are coded using International Disease Codes (ICD-10). Unique codes are provided for each medical procedure undertaken, with separate codes for primary and secondary medical procedures. The complexity of procedures is also recorded.

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

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

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

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

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

References

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

[2] 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.

[3] 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.

[4] 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.

[5] 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.

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

[9] BANDIERA.O, N.BUEHREN, M.GOLDSTEIN, I.RASUL AND A.SMURRA (2018) The Economic Lives of Young Women in the Time of Ebola: Lessons from an Empowerment Program, mimeo UCL.

[10] 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.

[11] 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.

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

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

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

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

[16] 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.

[17] 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: 1465-1510.

[18] CONTI.G, M.HANSON, H.INSKIP, S.CORZIER, C.COOPER AND K.GODFREY (2018) Beyond Birth Weight: The Origins of Human Capital, IFS WP W18/30.

[19] 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.

[20] CHRISTENSEN.D, O.DUBE, J.HAUSHOFER, B.SIDDIQI AND M.VOORS (2018) Healthcare Delivery During Crises: Experimental Evidence from Sierra Leone's Ebola Outbreak, mimeo, Chicago.

[21] 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.

[22] 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.

[23] 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.

[24] FLUCKIGER.M, M.LUDWIG AND A.SINA ONDER (2018) "Ebola and State Legitimacy," *Economic Journal*, forthcoming.

[25] FOGLI.A AND L.VELDKAMP (2016) Germs, Social Networks and Growth, NBER WP 18953.

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

[27] 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.

[28] 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.

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

[30] 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.

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

[32] LAM.D AND J.A.MIRON (1996) "The Effect of Temperature on Human Fertility," *Demography* 33: 291-305.

[33] MAFFIOLI.E (2018) The Political Economy of Health Epidemics: Evidence from the Ebola Outbreak, mimeo Michigan.

[34] 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.

[35] 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.

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

[37] 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.

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

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

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

[41] 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.

[42] QUINTENA-DOMEQUE.C, J.R.CARVALHO AND V.H. DE OLIVEIRA (2017) Zika Virus Prevalence, Correlates, and Preventive Behaviors: New Evidence from Survey Data, HCEO WP 2017-027.

[43] 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.

[44] 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.

[45] 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.

[46] 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.

[47] 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.

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

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

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

[51] ZWANE.A, J.ZINMAN, E.VAN DUSEN, W.PARIENTE, C.NULL, E.MIGUEL 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: Pregnancies, Behavior During Pregnancy and Congenital Malformations

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

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

	Control 1		**Control 2**		**Zika, Pre-Alert**		**Zika, Post-Alert**				
Estimated Dates of Conception:	**May-Oct 2013/14**		**Nov-Apr 2013/14**		**May-Oct 2015**		**Nov-Apr 2015/16**				
	Mean	Std. dev	Mean	Std. dev	Mean	Std. dev	Mean	Std. dev	**DID**	**Std. err**	**[p-value]**
A. Pregnancy											
Pregnancy Rate	4.24	(.990)	3.91	(1.01)	4.19	(.979)	3.57	(.985)	-.296	(.035)	[.000]
B. Behavior During Pregnancy											
Pregnancy Test Rate	6.39	(20.1)	8.32	(22.7)	12.4	(30.1)	14.1	(32.8)	-.197	(.776)	[.802]
Ultrasound Rate	248	(355)	250	(267)	250	(275)	275	(289)	22.4	(3.06)	[.000]
Abortion Rate	163	(173)	163	(158)	166	(154)	174	(166)	7.80	(2.49)	[.004]
Number of Prenatal Visits	7.68	(1.10)	7.80	(1.10)	7.81	(1.08)	7.91	(1.12)	-.016	(.025)	[.523]
C. Congenital Malformation (by dates of conception)											
Microcephaly Rate	.061	(1.16)	.768	(5.18)	.830	(4.50)	.529	(3.57)	-1.00	.404	[.019]
Other Congenital Malformation Rate	7.43	(13.9)	7.86	(14.9)	8.23	(14.4)	8.77	(16.4)	.110	.168	[.516]
# of City-month observations	56,776		55,496		27,550		26,401				
# of birth records	3,039,169		2,802,235		1,503,802		1,278,138				

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

Table 2: Pregnancy Rates

Dependent variable: Pregnancy Rate

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

Standard errors clustered by state in parentheses

Month of Pregnancy	(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]**
Difference-in-Difference	-.296***	-.296***	-.296***	-.306***	-.305***	-.306***	-.305***	
	(.035)	(.035)	(.035)	(.032)	(.031)	(.031)	(.032)	
	[-.368, -.222]	[-.367, -.223]	[-.368, -.222]	[-.371, -.241]	[-.368, -.241]	[-.369, -.242]	[-.370, -.240]	
Baseline Mean (DD % Impact)	4.24 (6.98%)	4.24 (6.98%)	4.24 (6.98%)	4.24 (7.21%)	4.24 (7.19%)	4.24 (7.21%)	4.24 (7.19%)	
Baseline Mean (South)								4.16
City of Residence Fixed Effects	Yes	No	Yes	Yes	Yes	Yes	Yes	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 pregnancy rate in the city-month. 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. Outcomes are derived from the SINASC birth records. Pregnancy rates are calculated considering the number of women starting their pregnancy per month per 1,000 women living in the same city. The population of women in the city is derived from DATASUS and is for 2012. Observations are weighted by the number of women in the city in 2012. The city of residence fixed effects cover 5,565 cities. In Column 4 onwards, the temperature controls include the city-month averages (derived from daily data) on temperature (in Celsius), wind speed (in kilometers), total insolation, precipitation (in millimeters), air humidity, maximum temperature (in Celsius) and min temperature (in Celsius). At the foot of each column, the difference-in-difference shows the difference between post and pre-alert impacts relative to earlier non-Zika years (and the corresponding percentage impact relative to the baseline mean). 95% confidence intervals are in brackets. Standard errors are clustered by state throughout.

Table 3: Behavior During Pregnancy

Dependent variables, Columns 1-4: Rates per 1,000 women pregnant in the last 3 city-months
Dependent variables, Column 5: Average per pregnant woman
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**	**(5) Number of Prenatal Visits**
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	.084***
	(1.24)	(1.24)	(5.70)	(6.48)	(4.11)	(4.86)	(.106)	(.024)
Aug_Oct x Zika$_t$ (Pre-Alert, 2nd Quarter)	5.36***	7.07***	-4.44	-5.48	1.00	1.21	-.112	.158***
	(1.19)	(1.14)	(5.03)	(5.79)	(3.82)	(4.54)	(.067)	(.022)
Nov_Jan x Zika$_t$ (Post-Alert, 1st Quarter)	4.41**	5.89***	9.92	11.24	5.37	6.50	-.165	.141***
	(1.20)	(1.29)	(6.18)	(6.89)	(3.26)	(3.82)	(.093)	(.015)
Feb_April x Zika$_t$ (Post-Alert, 2nd Quarter)	5.95**	7.90***	34.80***	39.25***	15.76***	18.55***	.414***	.073***
	(1.83)	(2.07)	(4.99)	(5.51)	(3.06)	(3.56)	(.083)	(.025)
Difference-in-Difference *(Post-Alert 2nd Quarter - Pre-Alert 2nd Quarter)*	.589	.833	39.2***	44.7***	14.7***	17.3***	.525***	-.085**
	(.988)	(1.34)	(4.93)	(5.32)	(3.26)	(3.82)	(.104)	(.033)
	[-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]	[-.153, -.016]
Baseline Mean (DD % 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%)	7.68 (1.09%)
City of Residence Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month of Event Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time Varying Controls (City-Month)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R-squared	.547	.532	.562	.515	.755	.700	.708	.810
Administrative Records Used	SIH/SIA	SIH/SIA	SIH/SIA	SIH/SIA	SIH/SIA	SIH/SIA	SIM	SINASC
# of City-month observations	189,535	79,933	189,535	88,873	189,535	76,477	41,391	190,110

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 outcome in Column 5 is defined as the average per pregnant women (as measured at the time of birth at the end of the pregnancy), and is derived from SINASC records. The city of residence fixed effects cover 5,565 cities. The temperature controls include the city-month averages (derived from daily data) on temperature (in Celsius), wind speed (in kilometers), total insolation, precipitation (in millimeters), air humidity, maximum temperature (in Celsius) and min temperature (in Celsius). At the foot of each column, the difference-in-difference shows the difference between the second quarter of post and pre-alert impacts relative to earlier non-Zika years (and the corresponding percentage impact relative to the baseline mean). 95% confidence intervals are in brackets. Standard errors are clustered by state throughout.

Table 4: Birth Outcomes

Dependent variables: Rates per 1,000 births in the city-month

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

Standard errors clustered by state in parentheses

Month of Conception	(1) C-Section Delivery	(2) Premature (=1 if < 37 wks)	(3) Low birth weight (< 2500g)	(4) Microcephaly	(5) Other Congenital Malformation
Zika$_t$, Pre-Alert (β_1)	-7.42***	-.299	1.75***	.808***	.817***
	(2.49)	(.887)	(.375)	(.166)	(.211)
Zika$_t$, Post-Alert (β_2)	-9.86***	1.67**	.675*	-.239	.895***
	(3.02)	(.715)	(.340)	(.271)	(.301)
Difference-in-Difference	-.2.44	1.97*	-1.07**	-1.04**	.078
	(2.82)	(.991)	(.448)	(.416)	(.180)
	[-8.25, 3.37]	[-.063, 4.01]	[-1.99, -.158]	[-1.90, -.191]	[-.292, .449]
Baseline Mean (DD % Impact)	571 (.427%)	120 (1.64%)	84.5 (1.26%)	.061 (1705%)	7.44 (1.04%)
Month of Conception Fixed Effects	Yes	Yes	Yes	Yes	Yes
City of Residence Fixed Effects	Yes	Yes	Yes	Yes	Yes
Time-Varying Controls (City-Month)	Yes	Yes	Yes	Yes	Yes
Adjusted R-squared	.711	.114	.056	.032	.068
Administrative Records Used	SINASC	SINASC	SINASC	SINASC	SINASC
# of City-month observations	190,423	190,423	190,423	190,423	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. Pregnancy dates are recovered using information on the last menstruation date, and by subtracting the number of gestational weeks or categories of length of gestation from the exact date of birth. In Column 4, microcephaly at birth is identified from IC-10 code Q02X. This analysis excludes mothers aged below 12 or older than 49. Outcomes are defined as the rate per 1000 births in the city-month. Observations are weighted by the population of women in the city in 2012. The city of residence fixed effects cover 5,565 cities. The temperature controls include the city-month averages (derived from daily data) on temperature (in Celsius), wind speed (in kilometers), total insolation, precipitation (in millimeters), air humidity, maximum temperature (in Celsius) and min temperature (in Celsius). At the foot of each column, the difference-in-difference shows the difference between the post and pre-alert impacts relative to earlier non-Zika years (and the corresponding percentage impact relative to the baseline mean). 95% confidence intervals are in brackets. Standard errors are clustered by state throughout.

Table 5: Health Care Personnel Behavior

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

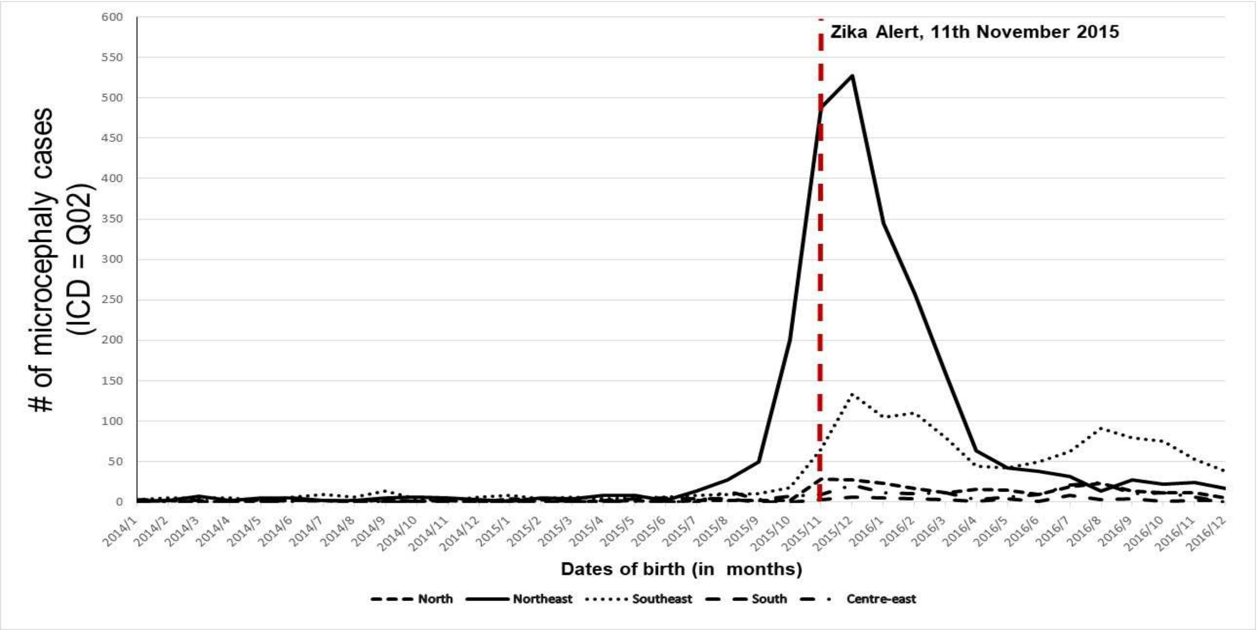
Standard errors clustered by state in parentheses

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) Confirmed 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)
Difference-in-Difference	.147*	.527***	.016***	.176***	.002	-.002	.805
	(.073)	(.073)	(.003)	(.053)	(.001)	(.001)	(1.01)
	[-.003, .297]	[.376, .678]	[.009, .022]	[.065, .286]	[-.0005, .005]	[-.005, .001]	[-1.27, 2.88]
Baseline Mean (DD % Impact)	.059 (249%)	.060 (878%)	.001 (1600%)	.012 (1466%)	.009 (22.2%)	.001 (200%)	33.0 (2.43%)
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	.791
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	189,528

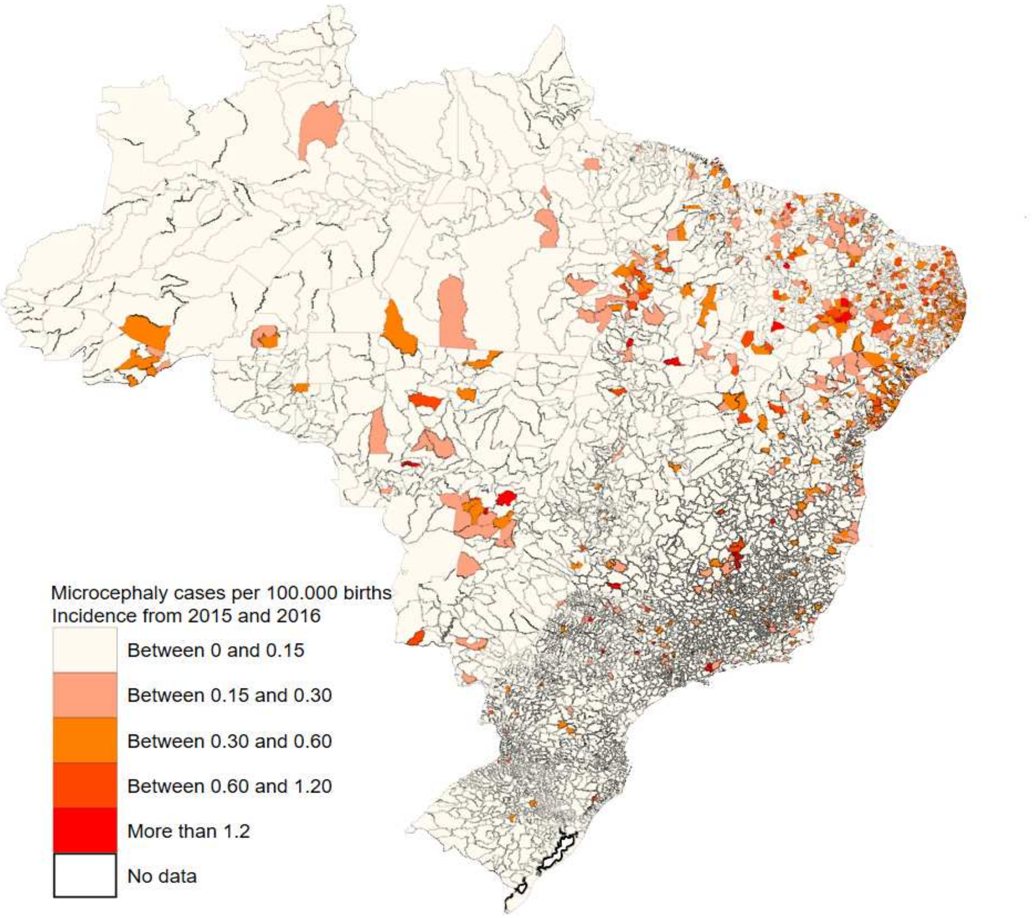
Notes: *** denotes significance at 1 percent, ** at 5 percent, and * at 10 percent level. The outcomes in Columns 1 to 3 are derived from the SINAN dengue database. The outcomes in Columns 4 onwards are derived from SIH/SIA inpatient-outpatient records. Months refers to the month of the outcome. In Columns 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, the difference-in-difference shows the difference between the post and pre-alert impacts relative to earlier per-epidemic years (and the corresponding percentage impact relative to the baseline mean). 95% confidence intervals are in brackets. Standard errors are clustered by state throughout.

Figure 1: Microcephaly

A. Time Series of Microcephaly Cases, by Region



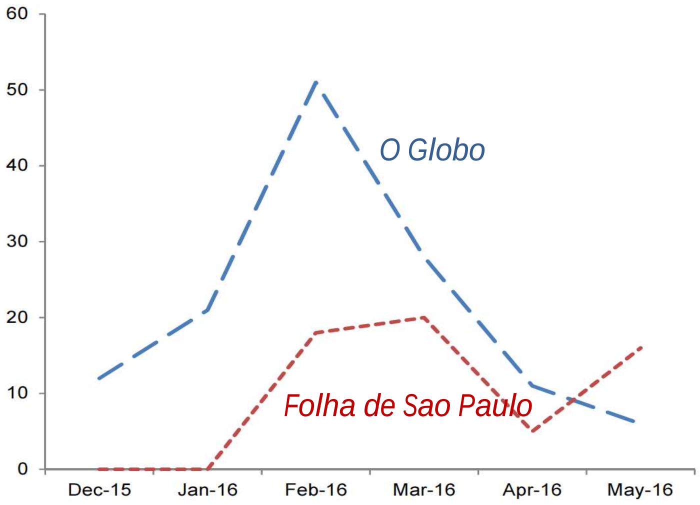
B. Spatial Incidence of Microcephaly Cases



Notes: Panel A in Figure I 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.

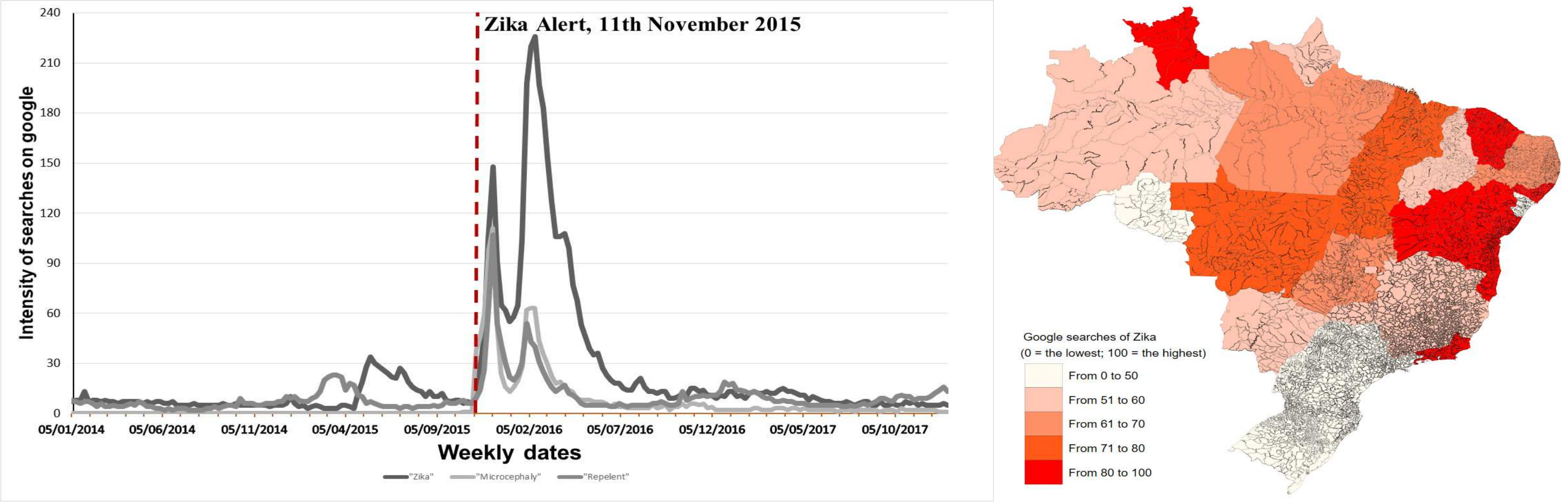
Figure 2: Public Awareness

A. Media Coverage, Ribeiro et al. [2018]



B. Google Searches for Zika, Microcephaly, Repellent

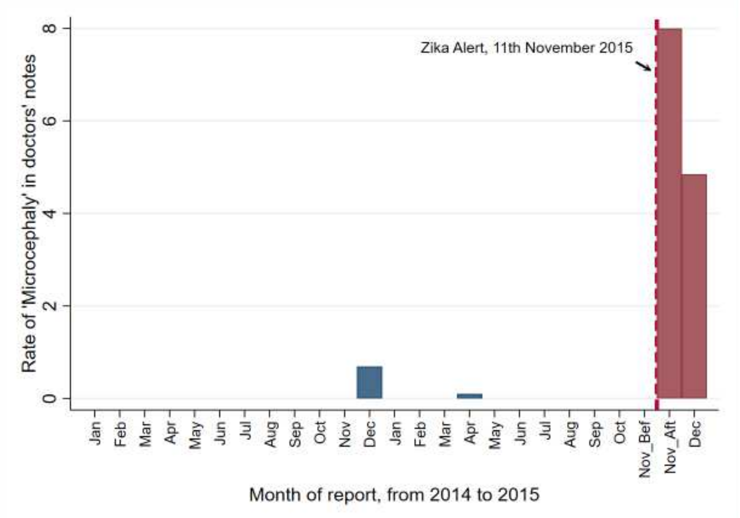
C. Spatial Variation in Google Searches for Zika

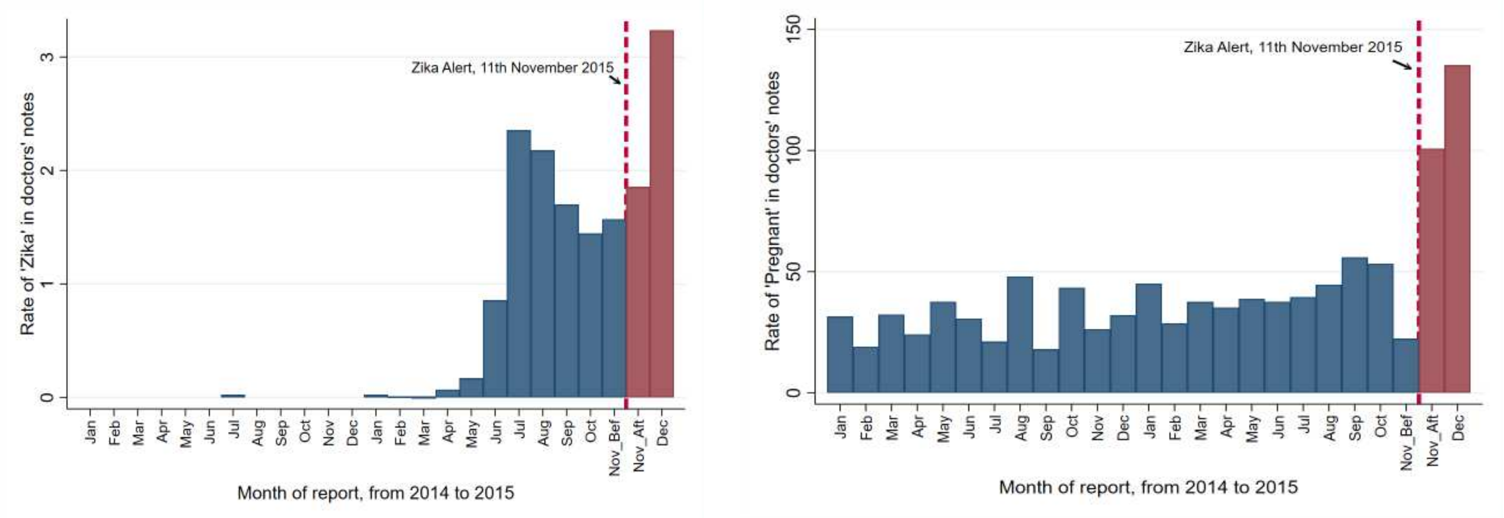


Notes: Panel A reproduces Ribeiro et al. [2018] showing media coverage of Zika Virus from December 2015 until May 2016 in O Globo and Folha de Sao Paulo newspapers. Panel B presents the intensity of Google searches for the following words: "Zika", "Microcephaly" and "Repellent" within Brazil over time. 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). 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 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



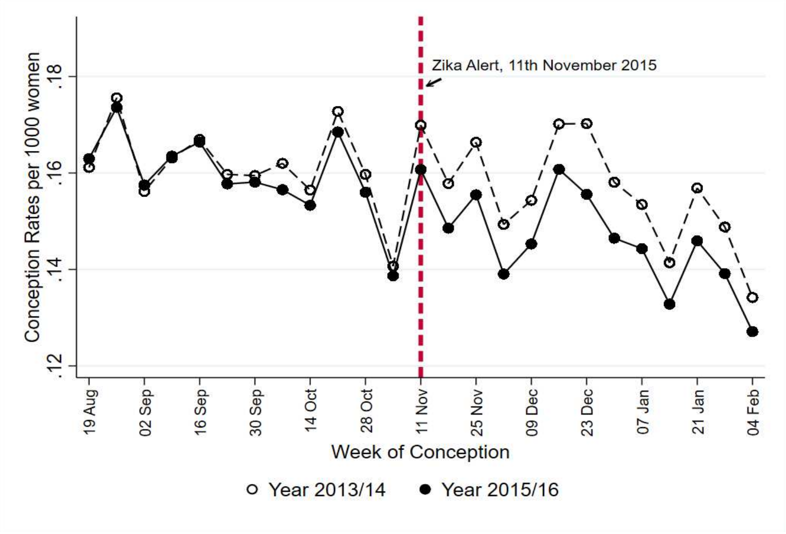


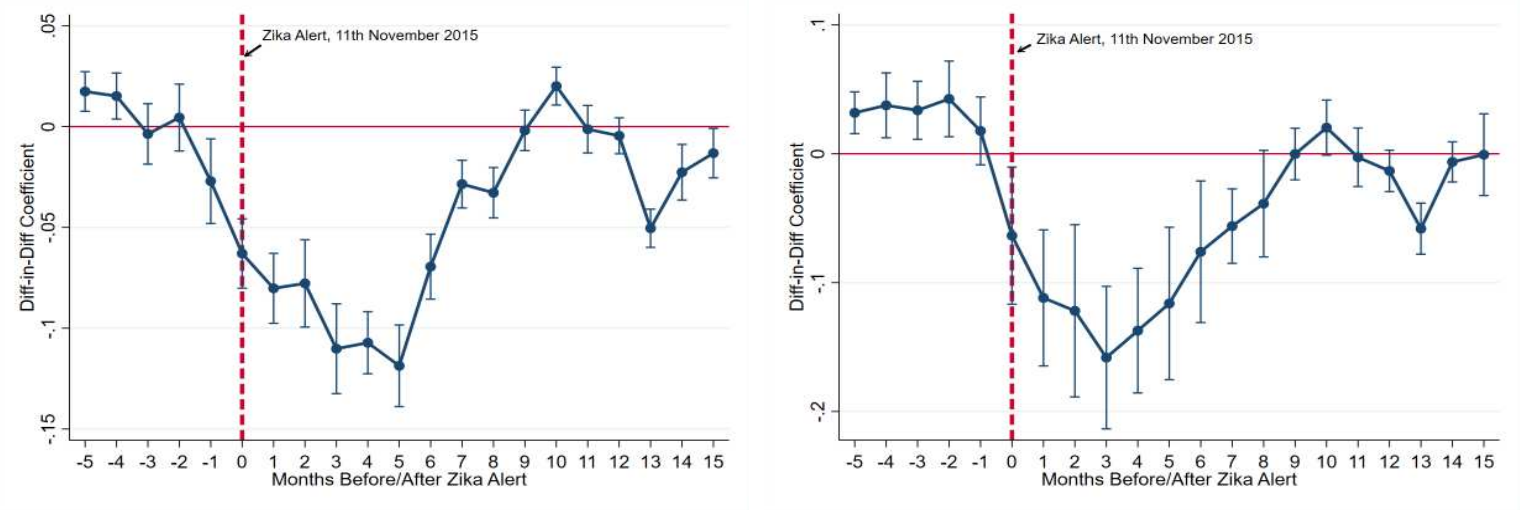
B. Incidence of "Zika" Written in Doctor's Notes

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

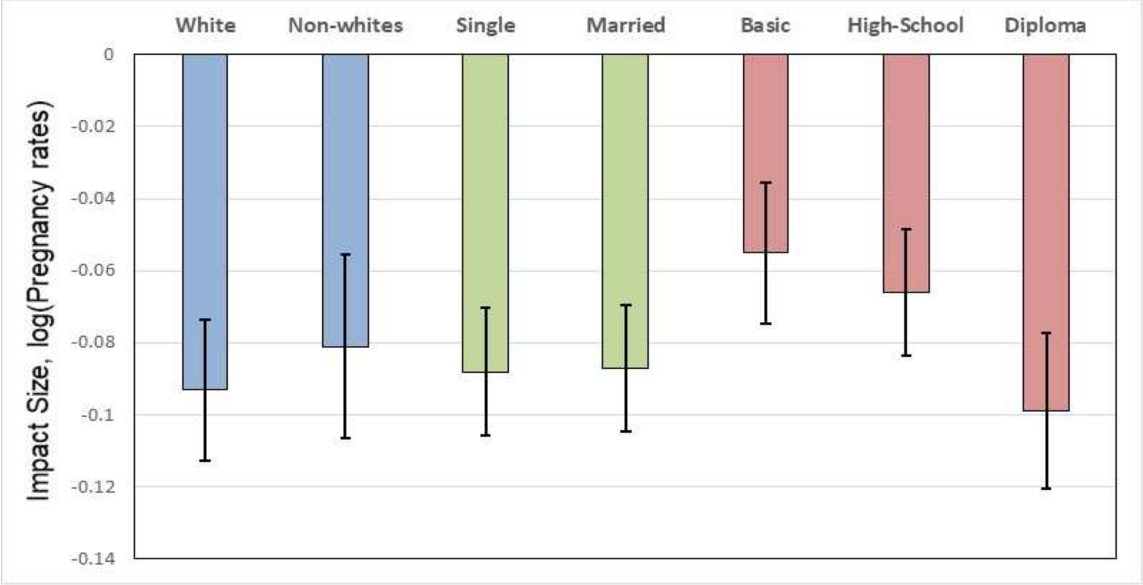

B. Dynamic Response Estimates

C. Dynamic Response Estimates (North East)

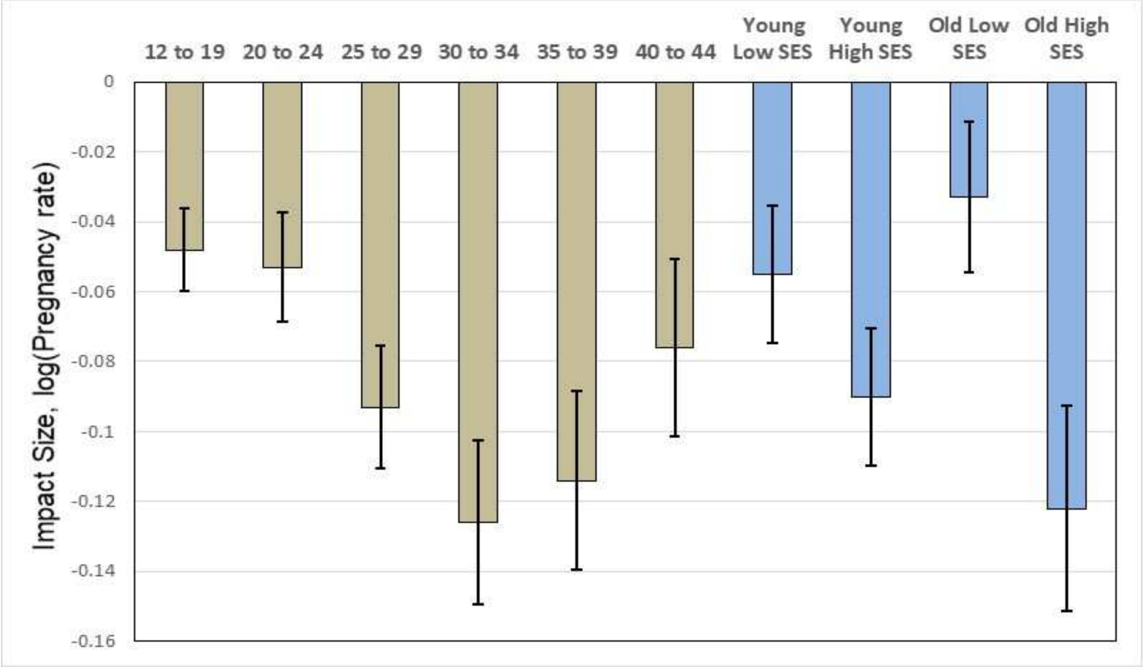
Notes: On the 11th November 2015 the Brazilian government officially announced the association between the upsurge of Zika and microcephaly in Northeastern Brazil. This is indicated by the vertical dashed line from Panels A to C. Panel A presents weekly changes in conceptions dates from the 33th to the 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 difference-in-difference 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



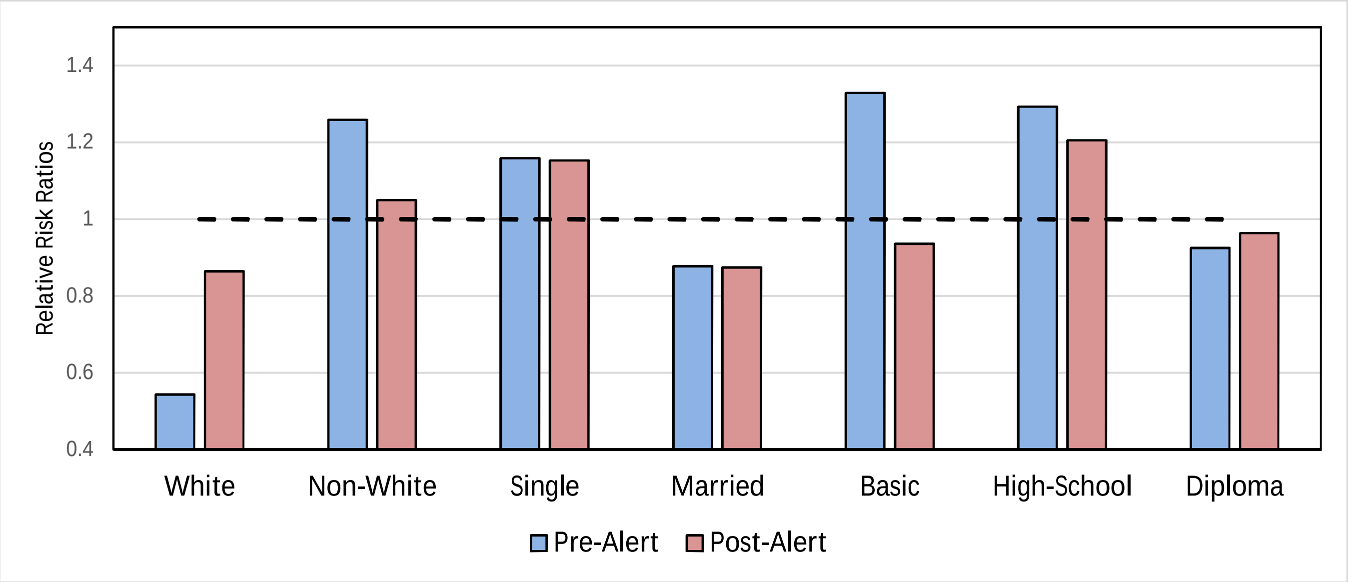
B. By Age and Socio-Economic Status



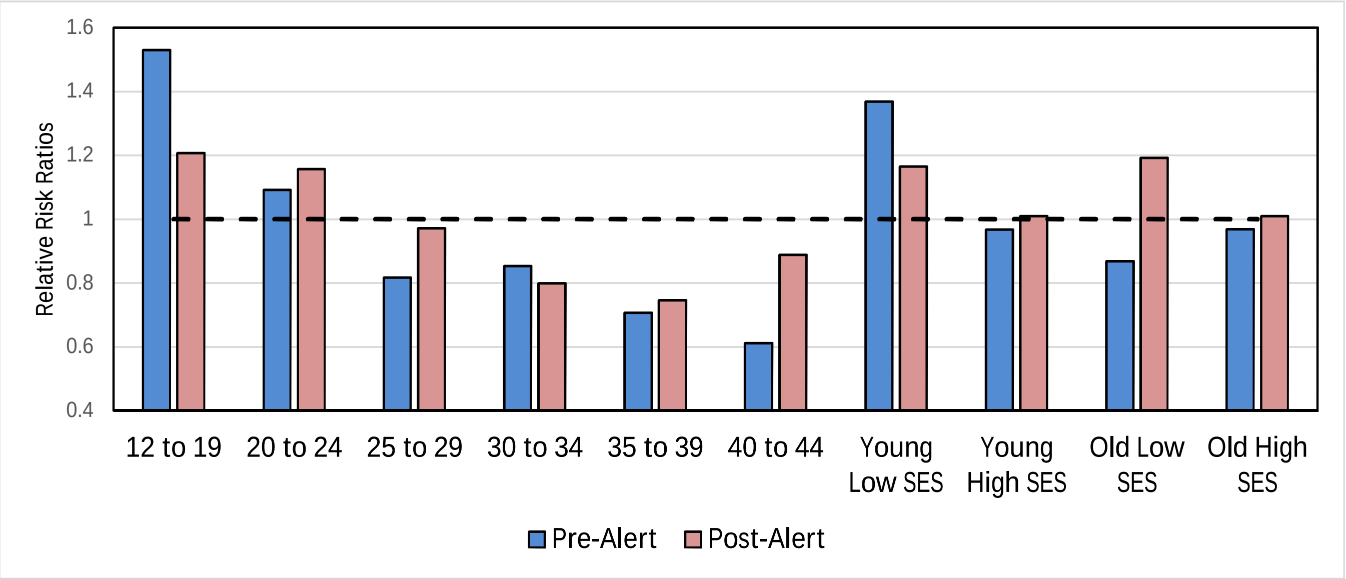
Notes: The Panels show the impacts of the Zika alert on conception rates among different subgroups, and the associated 90% confidence intervals. Non-white women are those reporting their race to be Black, Yellow, Parda and Native. The categories for mother's education include women with basic education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



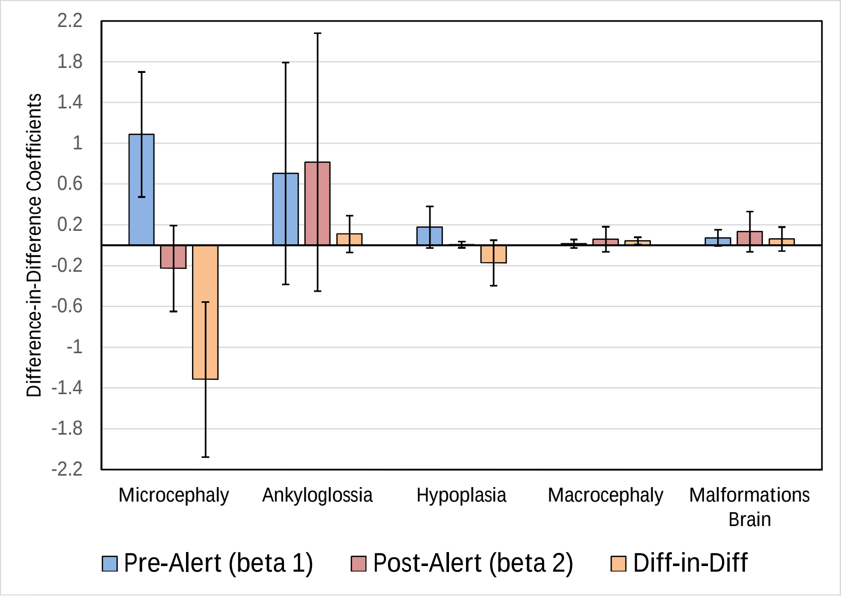
B. By Age and Socio-Economic Status



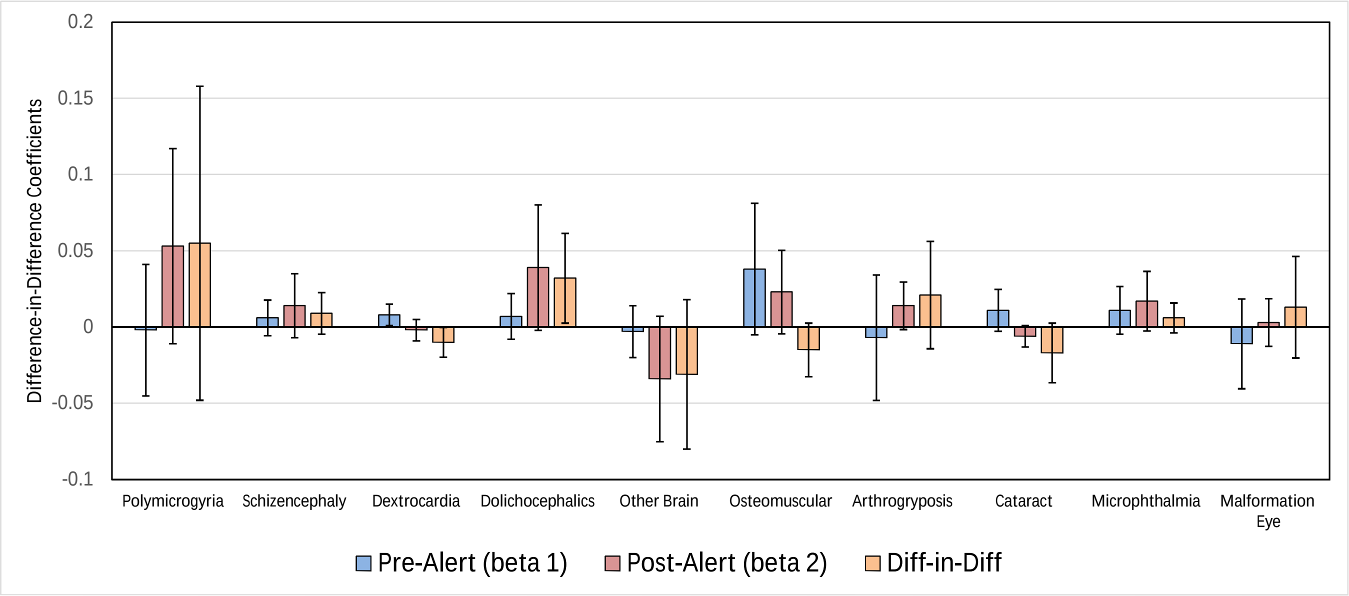
Notes: Figures A and B present the relative risk of having a child with microcephaly among different subgroups of mothers and their associated 95% confidence intervals. Pre-Alert periods in blue indicate (6 months before Zika Alert and Post Alert in red indicates 6 months after Zika Alert on 11 November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

Panel A



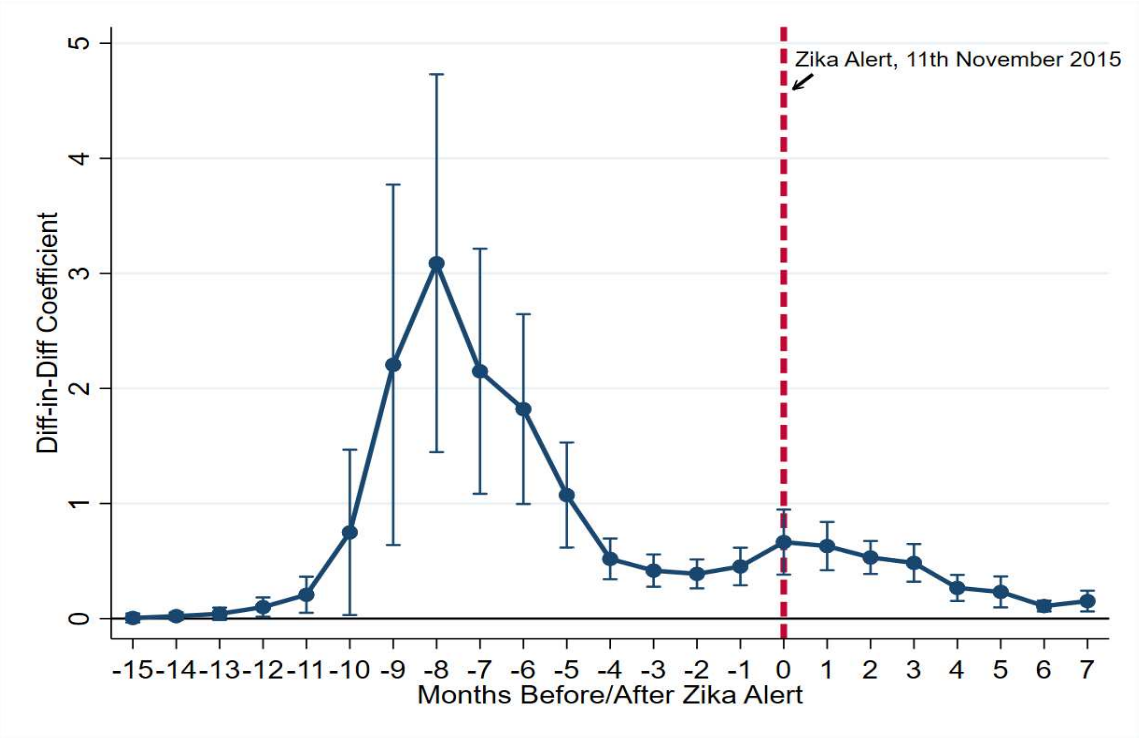
Panel B



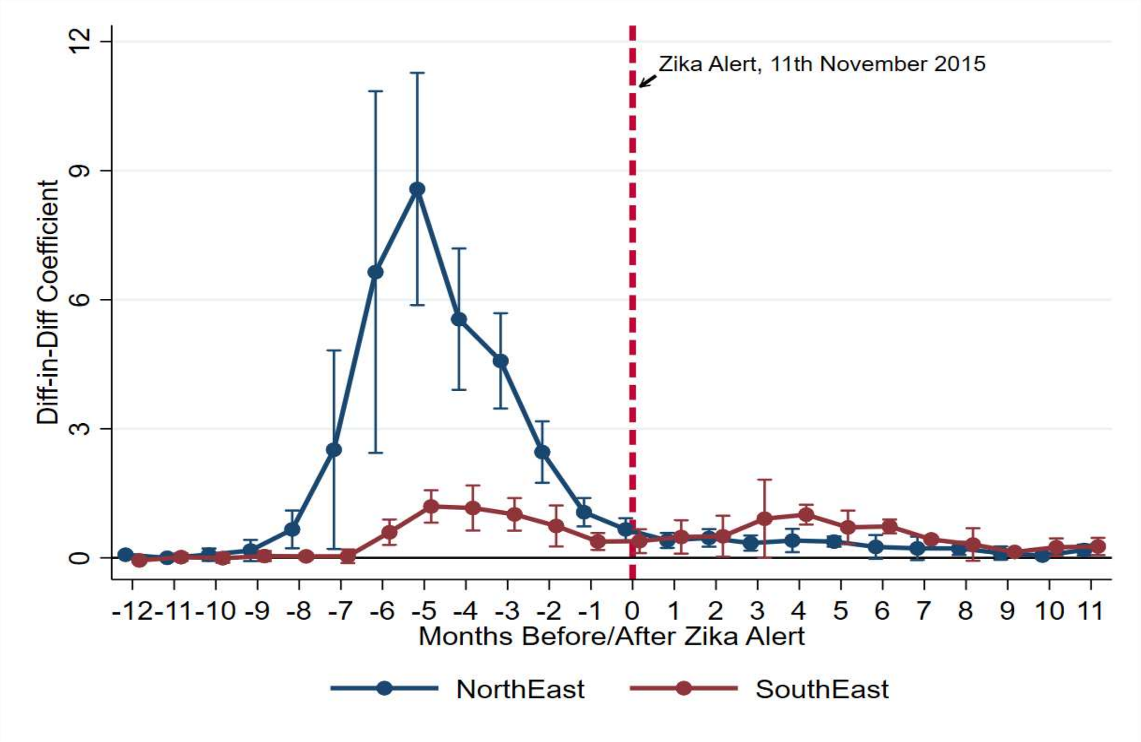
Notes: Panels A and B show the impacts of the Zika alert on congenital malformations and the corresponding 95% confidence intervals (where standard errors are clustered at state level on the underlying difference-in-difference regression). Light blue bars represent the Pre-Alert coefficient (beta 1), light red bars plot the Post-Alert coefficient (beta 2) and the light yellow bars are the difference-in-difference coefficient (beta 2 - beta 1). These estimates consider the number of congenital malformations (by month of conception) according to SINASC birth records and excludes mothers aged below 12 or older than 49. Observations are weighted by the number of women in the city in 2012. In Panel A, the group "Microcephaly" shows the number of births with ICD code Q02, "Ankyloglossia" refers to ICD code Q381, "Hypoplasia" refers to ICD code Q270, Macrocephaly refers to ICD code Q75.3 and Malformations in the brain refers to ICD codes Q040 until Q049. In Panel B, "Polymicrogyria" refers to ICD code Q043, "Schizencephaly" refers to ICD code Q046, "Dextrocardia" refers to ICD code Q240, "Dolichocephalics" refers to ICD code Q67.2, "Osteamucular" refers to other congenital deformities indicated by ICD code Q688, "Artrogripose" has ICD code Q743, congenital "Cataract" refers to ICD code Q120, "Microphthalmia" refers to ICD code Q112, and malformations in the eye refer to ICD codes between Q130 and Q159.

Figure 8: Microcephaly, Dynamics

A. At Conception

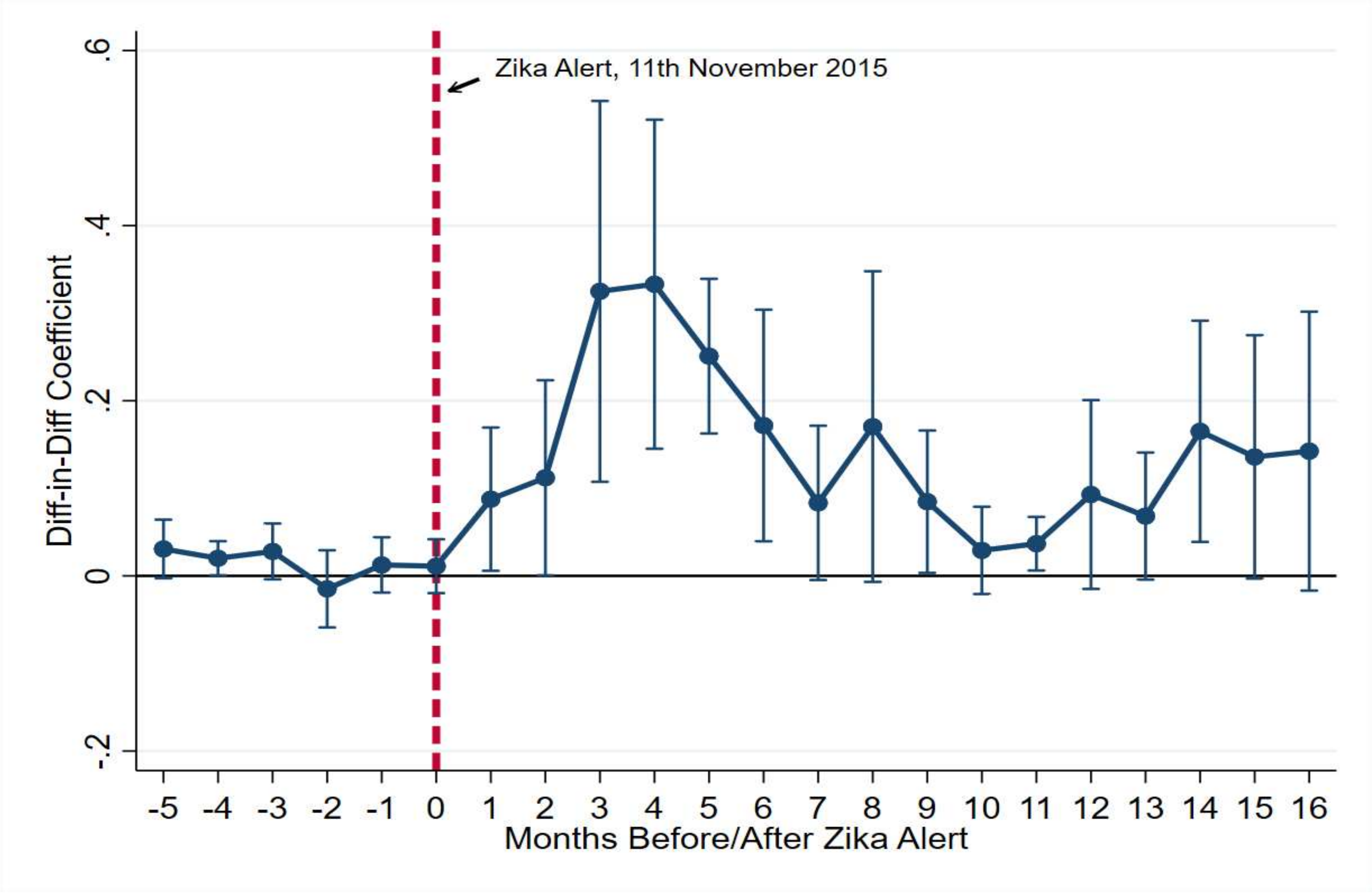


B. By Region



Notes: Both Panels presents the monthly difference-in-difference coefficients of microcephaly cases. Panel A does so for all of Brazil, Panel B plots the coefficients for North East and South East regions only. The dependent variable is the rate of microcephaly cases (IDC "Q02") on live births in SINASC per 1000 births in the city-month. The vertical line illustrates the Zika alert on 11th November 2015 which represents when the Brazilian government officially announced the association between the upsurge of Zika and microcephaly in Northeastern Brazil. The regressions used month -16 (sixteen months prior to the alert) as baseline. . The x-axis represents the number of months before and after the alert. The y-axis plots the coefficient and the associated 90% confidence interval. Standard errors are clustered by state in the underlying regression.

Figure 9. Diagnosed Cases of Zika



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

Table A1: Hospital Admission Rates

Dependent variable: Hospital admissions per 1000 population/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**	**(5) Baseline**	**(6) 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)
Difference-in-Difference	-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 (DD % Impact)	114 (.894%)	114 (1.03%)	16.2 (6.91%)	16.2 (7.09%)
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, the difference-in-difference shows the difference between post and pre-alert impacts relative to earlier non-Zika years (and the corresponding percentage impact relative to the baseline mean). 95% confidence intervals are in brackets. Standard errors are clustered by state throughout.

Table A2: Robustness Checks

Dependent variable, Columns 1 to 6: Pregnancy rate

Dependent variable, Columns 7 to 9: 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) City of Residence and Birth Differ	(8) City of Residence and Birth Differ, Abortion Available	(9) City of Residence and Birth Differ, City Ultrasound Available
Zika$_t$, Pre-Alert (β_1)	-.013	.002	.004	-.013	.048*	-.010	.008**	-.017	-.015
	(.019)	(.018)	(.012)	(.020)	(.021)	(.022)	(.002)	(.020)	(.020)
Zika$_t$, Post-Alert (β_2)	-.319***	-.303***	-.267***	-.321***	-.255***	-.350***	.005**	-.324***	-.328***
	(.032)	(.031)	(.035)	(.033)	(.029)	(.035)	(.002)	(.030)	(.033)
Difference-in-Difference	-.306***	-.305***	-.270***	-.308***	-.303***	-.340***	-.001	-.306***	-.312***
	(.032)	(.030)	(.035)	(.032)	(.030)	(.035)	(.001)	(.030)	(.033)
	[-.371, -.241]	[-.368, -.242]	[-.343, -.198]	[-.374, -.241]	[-.366, -.241]	[-.411, -.268]	[-.003, .000]	[-.369, -.243]	[-.382, -.242]
Baseline Mean (DD % Impact)	4.24 (7.21%)	4.24 (7.19%)	4.09 (6.60%)	4.25 (7.24%)	4.18 (7.24%)	4.53 (7.50%)	.309 (.323%)	4.26 (7.18%)	4.25 (7.34%)
City of Residency Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month of Conception Fixed effects	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time Varying Controls (City-Month)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R-squared	.601	.586	.357	.626	.582	.629	.962	.707	.689
Administrative Records Used	SINASC	SINASC	SINASC	SINASC	SINASC	SINASC	SINASC	SINASC & SIA/SIH	SINASC & SIA/SIH
# of City-month observations	190,424	190,424	190,424	156,200	255,130	190,424	190,418	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 6 is the pregnancy rate in the city-month. 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. Outcomes are derived from the SINASC birth records. Pregnancy 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. In Columns 7 to 9 the outcome is the share of women giving birth in the city-period whose city of residence and city of birth differ. The city of residence fixed effects cover 5,565 cities. The temperature controls include the city-month averages (derived from daily data) on temperature (in Celsius), wind speed (in kilometers), total insolation, precipitation (in millimeters), air humidity, maximum temperature (in Celsius) and min temperature (in Celsius). At the foot of each column, the difference-in-difference shows the difference between post and pre-alert impacts relative to earlier non-Zika years (and the corresponding percentage impact relative to the baseline mean). 95% confidence intervals are in brackets. Standard errors are clustered by state throughout.

Table A3: Birth Outcomes by the Availabiltiy of Abortions, Ultrasounds

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

	A. Premature (=1 if < 37 wks)				**B. Low birth weight (< 2500g)**			
Month of Conception	Ultrasound Available	No Ultrasound Available	Abortion Available	No Abortion Available	Ultrasound Available	No Ultrasound Available	Abortion Available	No Abortion Available
Zika$_t$, Pre-Alert (β_1)	-.614	1.70	-.578	1.04	1.58***	2.73***	1.66***	2.06**
	(.934)	(1.12)	(.899)	(1.29)	(.409)	(.703)	(.388)	(.789)
Zika$_t$, Post-Alert (β_2)	1.44*	3.21*	1.45*	2.80**	.456	2.06**	.368	2.19***
	(.749)	(1.65)	(.735)	(1.35)	(.414)	(.967)	(.451)	(.768)
Difference-in-Difference	2.05*	1.50	2.03*	1.76	-1.13**	-.673	-1.29**	.128
	(1.07)	(1.76)	(1.06)	(1.74)	(.513)	(.998)	(.551)	(1.16)
	[-.156, 4.27]	[-2.12, 5.13]	[-.167, 4.22]	[-1.84, 5.36]	[-2.18, -.075]	[-2.72, 1.38]	[-2.42, -.164]	[-2.27, 2.53]
Baseline Mean (DD % Impact)	119.7 (.017%)	119.3 (.012%)	119.9 (.016%)	118.3 (.014%)	85.7 (.013%)	75.8 (.008%)	86.0 (.015%)	76.4 (.001%)
Month of Conception Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City of Residence Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-Varying Controls (City-Month)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R-squared	.184	.044	.204	.040	.094	.016	.105	.016
Administrative Records Used	SINASC	SINASC	SINASC	SINASC	SINASC	SINASC	SINASC	SINASC
# of City-month observations	88,950	101,473	76,557	113,866	88,950	101,473	76,557	113,866

	C. Microcephaly				**D. Other Congenital Malformation**			
Month of Conception	Ultrasound Available	No Ultrasound Available	Abortion Available	No Abortion Available	Ultrasound Available	No Ultrasound Available	Abortion Available	No Abortion Available
Zika$_t$, Pre-Alert (β_1)	.808***	.813***	.780***	.958***	.887***	.323	.872***	.530**
	(.167)	(.196)	(.169)	(.179)	(.206)	(.301)	(.216)	(.235)
Zika$_t$, Post-Alert (β_2)	-.207	-.473*	-.171	-.603*	.923***	.666*	.915**	.783***
	(.278)	(.233)	(.256)	(.333)	(.309)	(.357)	(.331)	(.236)
Difference-in-Difference	-1.01**	-1.28***	-.951**	-1.56***	.035	.342	.043	.252
	(.425)	(.408)	(.400)	(.479)	(.184)	(.336)	(.205)	(.220)
	[-1.88, -.140]	[-2.12, -.444]	[-1.77, -.127]	[-2.54, -.572]	[-.344, .415]	[-.350, 1.03]	[-.379, .466]	[-.202, .707]
Baseline Mean (DD % Impact)	.063 (16.0%)	.050 (25.6%)	.062 (15.3%)	.059 (26.4%)	7.56 (.004%)	6.61 (.051%)	7.56 (.005%)	6.78 (.037%)
Month of Conception Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City of Residence Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-Varying Controls (City-Month)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R-squared	.050	.010	.062	.012	.140	.010	.158	.011
Administrative Records Used	SINASC	SINASC	SINASC	SINASC	SINASC	SINASC	SINASC	SINASC
# of City-month observations	88,950	101,473	76,557	113,866	88,950	101,473	76,557	113,866

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

Table A4: 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

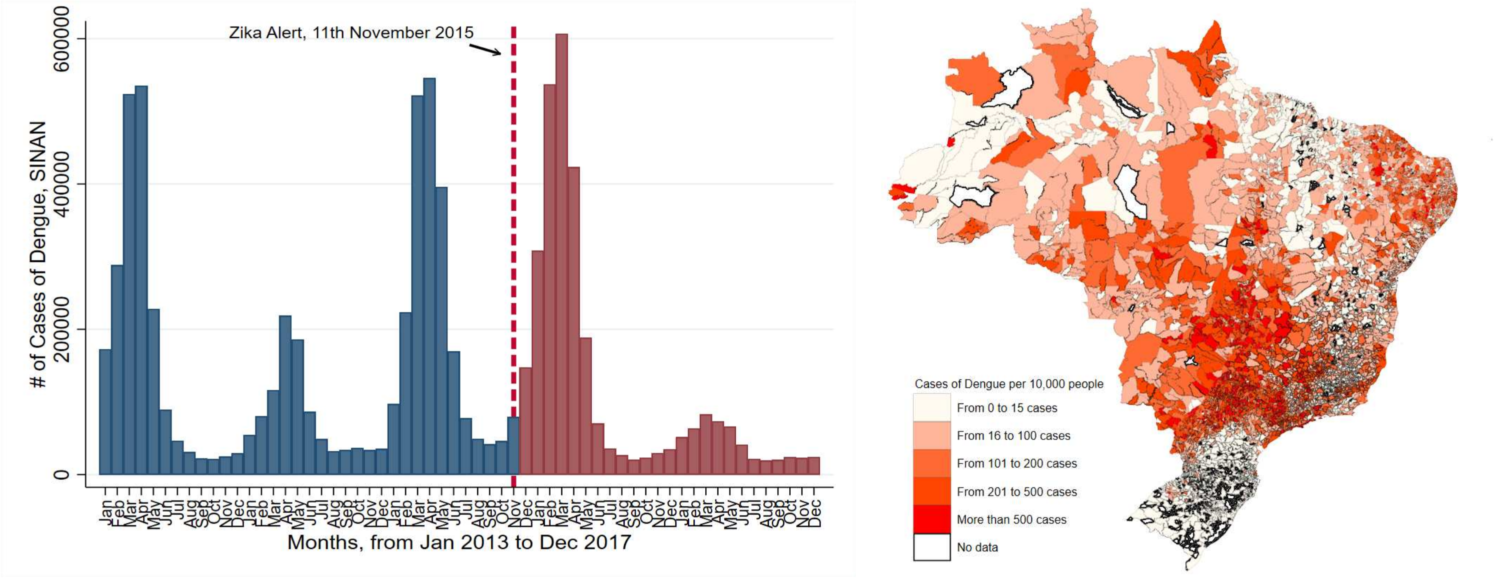
Month of Outcome	(1) Dengue Tests Administered to Pregnant Women	(2) Negative Dengue Test Results in Pregnant Women	(3) Inconclusive Dengue Test Results in Pregnant Women
Zika$_t$, Pre-Alert (β_1)	.016	.006	-.000
	(.017)	(.016)	(.001)
Zika$_t$ Post-Alert x North East	.063	.520**	.017*
	(.047)	(.198)	(.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

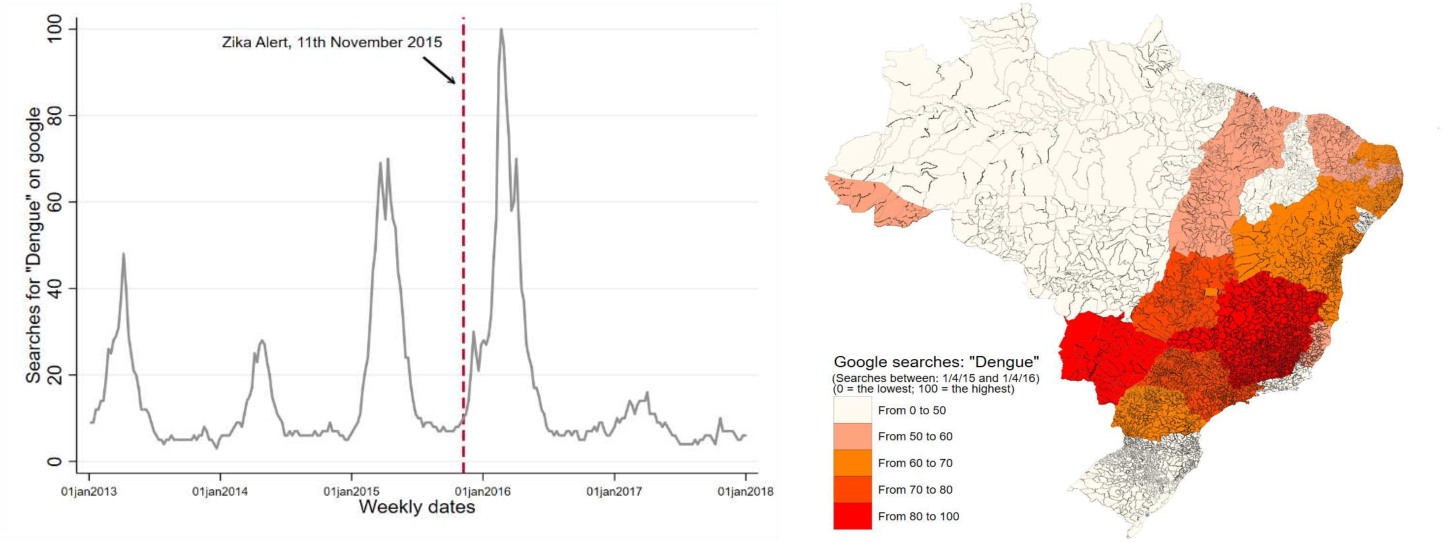
A. SINAN Records for Dengue (ICD = A91)

B. Spatial Variation in Dengue Incidence



C. Google Searches for "Dengue"

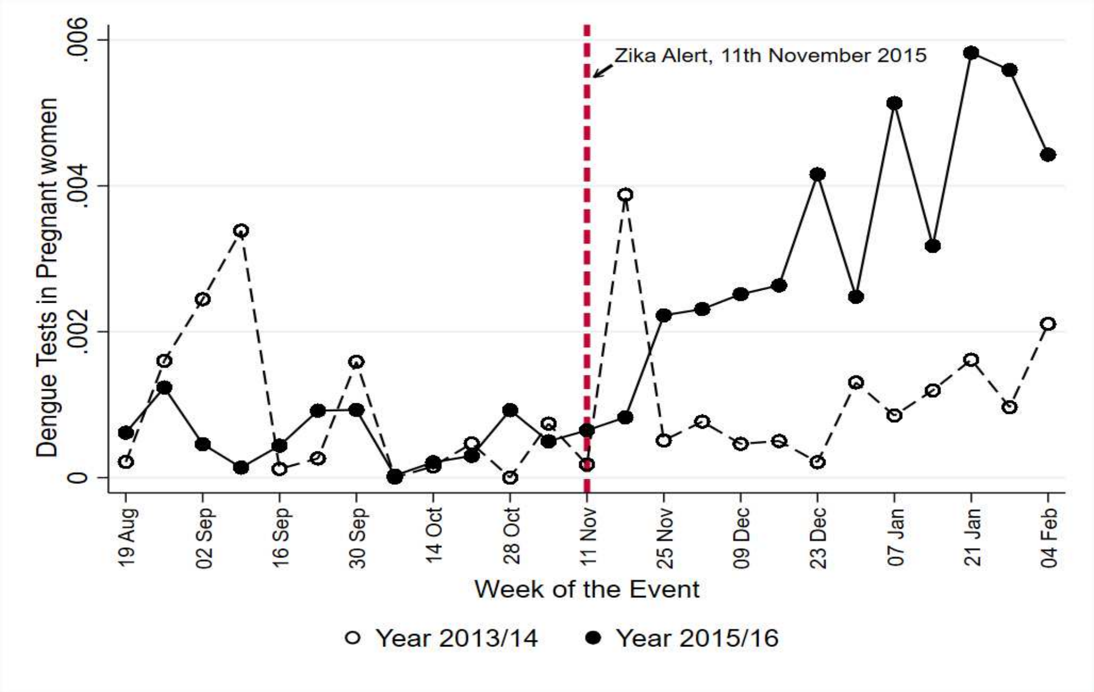
D. Spatial Variation in Google Searches for Dengue



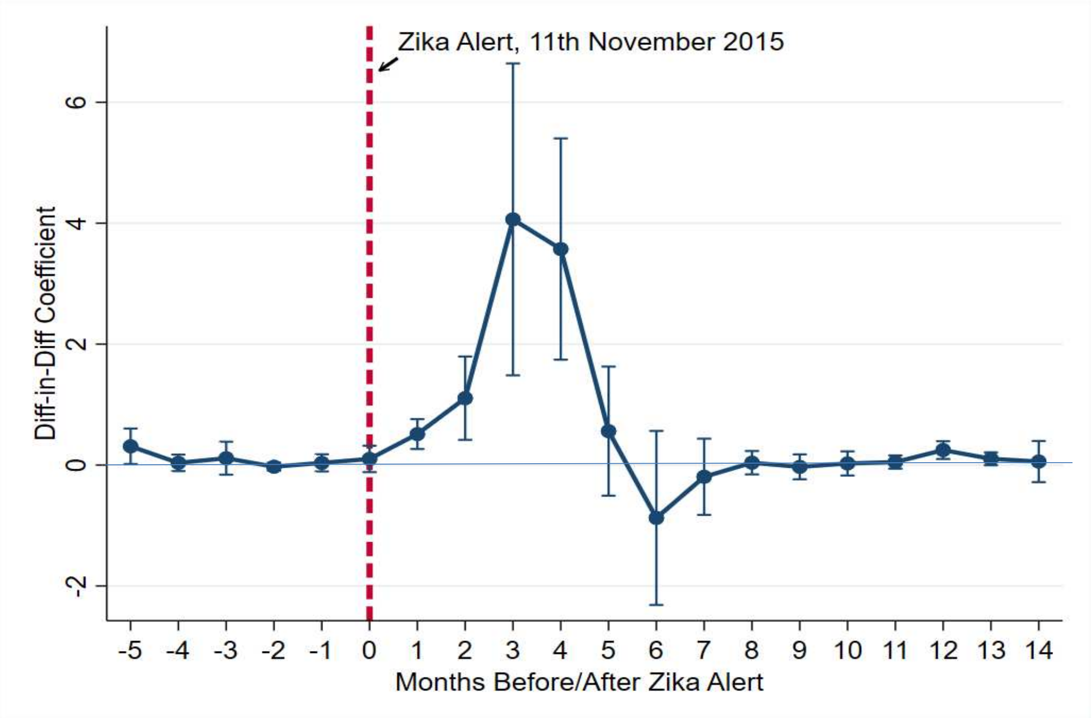
Notes: The time series in suspected or confirmed dengue cases is shown in Panel A. Panel B maps the incidence of dengue per 10,000 people living in cities, for suspected or confirmed cases during 2015 and 2016. Panel C shows the intensity of Google searches for "Dengue" and Panel D presents the spatial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

Figure A2: Administration of Dengue Tests to Pregnant Women, Dynamics

A. Dengue Tests, by Week



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 Difference-in-Difference 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.