Published in final edited form as:
Demography. 2020 June ; 57(3): 843–872. doi:10.1007/s13524-020-00871-x.

Live Births and Fertility Amid the Zika Epidemic in Brazil

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Abstract

In late 2015, the Brazilian Ministry of Health and the Pan American Health Organization classified the increase in congenital malformations associated with the Zika virus (ZIKV) as a public health emergency. The risk of ZIKV-related congenital syndrome poses a threat to reproductive outcomes that could result in declining numbers of live births and potentially fertility. Using monthly microdata on live births from the Brazilian Information System on Live Births (SINASC), this study examines live births and fertility trends amid the ZIKV epidemic in Brazil. Findings suggest a decline in live births that is stratified across educational and geographic lines, beginning approximately nine months after the link between ZIKV and microcephaly was publicly announced. Although declines in total fertility rates were small, fertility trends estimated by age and maternal education suggest important differences in how Zika might have impacted Brazil's fertility structure. Further findings confirm the significant declines in live births in mid-2016 even when characteristics of the municipality are controlled for; these results highlight important nuances in the timing and magnitude of the decline. Combined, our findings illustrate the value of understanding how the risk of a health threat directed at fetuses has led to declines in live births and fertility.

Keywords

Fertility; Birth rates; Brazil; Latin America; Zika

Introduction

The Zika virus (ZIKV) was first reported in the Americas in Brazil in 2014, with the majority of initial cases occurring in the northeast (Brasil 2015a; Pan American Health Organization 2015a, b, c). In late 2015, Brazil's Ministry of Health classified the increase in microcephaly and other congenital malformations associated with ZIKV to be a public health emergency (Brasil 2015b). Shortly thereafter, the Ministry announced the association

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between ZIKV and microcephaly, the most common manifestation of congenital Zika syndrome (CZS) (Brasil 2015c). Subsequently, the Pan American Health Organization (PAHO) declared Zika a public health emergency of international scale (Pan American Health Organization 2016).

In Brazil, 3,474 confirmed cases of ZIKV-related growth and developmental abnormalities were confirmed between 2015 and 2019 (Brasil 2019). The threat of congenital malformations owing to prenatal ZIKV infection may have led some women to delay childbearing or to terminate pregnancies despite highly restrictive abortion laws (Aiken et al. 2016). In the aggregate, these behaviors could lead to a decline in the number of live births and, ultimately, to changes in fertility rates and patterns.

A central line of inquiry in population research assesses whether live births and fertility change in response to shocks. Past research has documented fertility change as a consequence of shocks brought about by economic crisis (Sobotka et al. 2011; Vrachnis et al. 2014), public health emergencies (Trinitapoli and Yeatman 2011), wars (Agadjanian and Prata 2002), and natural disasters (Behrman and Weitzman 2016; Finlay 2009; Nobles et al. 2015). However, no study has examined trends in *both* live births and fertility after an epidemic that centers squarely on reproductive health, with potential dire consequences for newborns. There is also a lack of research examining the heterogeneous effects of epidemics, particularly regarding differences in the onset and severity.

Brazil’s Ministry of Health suggested the association between ZIKV and CZS, including microcephaly, in November 2015 (Brasil 2015c). Intense national and international media coverage followed the announcement,[1] and public interest in microcephaly peaked in November 2015,[2] with publications in scientific journals following (i.e., Calvet et al. 2016; Mlakar et al. 2016). In the midst of the emergency crisis, government officials released statements requesting that women postpone pregnancies. Although these pronouncements were subsequently criticized (Schuck-Paim et al. 2016), they were widely circulated and in line with public statements by doctors around the country (see McNeil 2015).

Given that the average pregnancy lasts approximately nine months, any change in live birth rates owing specifically to pregnancy delays would have become observable no earlier than August 2016. Changes due to pregnancy termination and miscarriage could have taken place sooner. Adding to the complexity, fertility at the onset of the epidemic was already below replacement levels in Brazil (Camarano 2014; Cavenaghi and Berquó 2014; Lima et al. 2018; Rios-Neto et al. 2018). Given the high level of unintended births (Le et al. 2014), it is also possible that the ZIKV epidemic had little to no effect on pregnancy avoidance and, therefore, on live births and fertility trends. It is also likely that given persistent socioeconomic, educational, and geographic differences in the country’s live births and fertility levels (Camarano 2014; Cavenaghi and Berquó 2014; Lima et al. 2018; Rios-Neto et al. 2018), the effects of the epidemic may have varied spatially and sociodemographically.

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[1] Statements linking ZIKV to CZS, including microcephaly, were widely announced in Brazilian and international media starting in November 2015, as evidenced through various reports (“On Saturday” 2015; “Ministry of Health confirms” 2015; Sims 2015) and as discussed at length elsewhere (Diniz 2016).

[2] The number of Google searches for the word “microcefalia” went from zero to its highest ever in November 2015.

Further, because the ZIKV epidemic spread first across the northeast states, yielding variation in the occurrence of and exposure to microcephaly cases over time,[3] declines in birth rates may also have varied spatially in conjunction with the local onset of the epidemic.[4]

We examine each of these possibilities using monthly data on live births from Brazil's Ministry of Health. Although some recent research has shown declines in live births (Castro et al. 2018; Marteleto et al. 2017), it is unclear whether such tendencies were homogenous across women's ages or educational groups, or whether they led to declines in fertility rates and patterns in states affected differently by the epidemic. Also unclear is whether these fertility declines hold when municipality factors are isolated. The way live births and fertility changed throughout the ZIKV epidemic may also differ across local communities because of their socioeconomic and demographic characteristics. Isolating the effects of the epidemic is made even more complicated by Brazil's concomitant economic crisis, which began in 2014. During the crisis, GDP fell from US$ 2.456 trillion in 2014 to US$ 1.796 trillion in 2016, and unemployment doubled from 6.9% in 2013 to 12.8% in 2017 (World Bank 2018).

This study has two overarching goals. The first is to investigate whether recent trends in live births, fertility rates, and fertility age patterns have changed amid the ZIKV epidemic in Brazil, the country most affected by this public health shock. Because of long-standing educational and geographic differences in Brazil's fertility and live birth patterns, and also in the emergence and intensity of the ZIKV threat across the country's large territory, the second goal is to examine whether changes in live births and fertility were conditioned by educational level and geographic location (state). By examining national- and state-level trends, we isolate local conditions at the municipality level because Brazil's different socioecomic and demographic municipalities might have impacted fertility change in different ways.

Literature Review

Live Births and Fertility in Brazil

Brazil's fertility rate fell dramatically from 6.15 births per woman in the 1970s to 1.83 in 2010 (Amaral et al. 2016; Instituto Brasileiro de Geografia e Estatística (IBGE) 2012), with areas with high overall levels of education taking the lead (Martine 1996; Potter et al. 2010). Nearly 20% of births in Brazil are to adolescents (Schuck-Paim et al. 2016), and the country's fertility schedule remains young despite its low total fertility rate (Cavenaghi and Berquó 2014; Rodriguez and Cavenaghi 2017). In addition, more than one-half of Brazilian births are unintended, with large differences across socioeconomic strata (Le et al. 2014). Because such a large proportion of births are to young women and are unintended, ZIKV may have affected the age pattern of fertility, especially because young women might have

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[3] We refer to the concept of *social exposure*—that is, to changes within one's social environment that may affect their thinking, behavior, intentions, and/or well-being. In this particular case, we refer to individuals' social exposure to microcephalic babies and children.

[4] In work in progress, Rangel and colleagues (forthcoming) have also found evidence of large changes in birth rates in Brazil during the epidemic, using an index of mosquito infestation to leverage the spread of the ZIKV epidemic across Brazil's microregions.

become more motivated to prevent unwanted pregnancies and postpone pregnancy, whereas older women prioritized acting on their shorter reproductive window despite the threat (Marteleto et al. 2017). ZIKV may therefore have resulted in a shift in the age pattern of fertility.

At the same time, a key feature of fertility in Brazil is that educational differences have persisted despite overall low fertility levels, with women with low levels of schooling having, on average, 1.8 children more than women with a college degree (Cavenaghi and Berquó 2014). Thus, responses to the ZIKV epidemic were likely heterogeneous across age and education. Because high-educated women have children later than their low-educated counterparts (Cavenaghi and Berquó 2014; Lima et al. 2018; Rios-Neto et al. 2018), there was potentially little room for significant fertility declines among the high-educated group. Although the ZIKV epidemic caught all women unexpectedly, high-educated women had less time than their low- socioeconomic status (SES) counterparts to act on their desired fertility because of their later mean age at childbearing. Therefore, how fertility differed by educational level throughout the epidemic might have been conditioned by age. High-educated women might have continued in their childbearing path despite the epidemic. On the other hand, because the fertility rate was already low among high-educated women at the start of the ZIKV epidemic, the perceived threat of ZIKV may have only slightly changed trends in live births as well as in women's birth timing and spacing intentions, but not enough to cause an impact in period or cohort fertility. High-educated women have shown high levels of agency regarding their childbearing and full access to contraceptive options throughout the ZIKV epidemic (Marteleto et al. 2017). Although both high- and low-educated women were equally concerned with childbearing during the epidemic, the former were more able to translate intentions into action within their reproductive health arena because of their greater access to contraception and higher-quality health care; these women were also better able to implement strategies to avoid mosquito bites, such as repellent use (Marteleto et al. 2017).

Whether measured through education or income, SES works largely in the same direction in shaping fertility outcomes in Brazil (Cavenaghi and Berquó 2014; Coutinho 2016; Lam and Duryea 1999; Lima et al. 2018; Marteleto and Dondero 2013; Potter et al. 2010; Rios-Neto et al. 2018). High-educated women are effective in implementing their fertility preferences, and their low-educated counterparts have higher rates of unintended pregnancy (Coutinho 2016) and lower mean age at childbearing (Cavenaghi and Alves 2009; Itaborai 2015). At the same time, low-educated women have lower access to oral contraception (Borges et al. 2016) and present lower rates of condom use (Nascimento et al. 2017).

Similar to socioeconomic differences in contraceptive use, abortion[5] is also highly variable across educational lines in Brazil. Specifically, abortion is more frequent among the socially

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[5] Abortion is mostly illegal in Brazil, but it is nonetheless frequent (Diniz and Medeiros 2010; Diniz et al. 2017). A 2016 national household survey using ballot box techniques suggests that one in every five women will have had an abortion by age 40, with abortion more commonly occurring among young women up to age 24 (Diniz et al. 2017). The only data available on abortion in Brazil are hospital admittances owing to abortion complications; to estimate abortion, it is necessary to make assumptions that the characteristics of the women seeking hospitalization after the procedure did not change with the Zika epidemic (Singh and Wulf 1991).

disadvantaged, with a large proportion using drugs for induction purchased in underground markets (Diniz and Medeiros 2010). The type and circumstances of abortion procedures also vary for women with low versus high educational levels: unsafe abortion is more common among low-educated women (Martins-Melo et al. 2014; Menezes and Aquino 2009), leading to one death due to the practice every other day (Dip 2013).

How the ZIKV epidemic affected live births and fertility also likely differed according to women's educational levels because ZIKV disproportionately affected poorer populations in Brazil (Ali et al. 2017), similar to other mosquito-borne diseases and to sexually transmitted infections (Silva et al. 2009; Siqueira et al. 2004; Szwarcwald et al. 2005). Poorer populations tend to have precarious access to infrastructures that protect against mosquito breeding (e.g., a lack of piped water) (Ferreira et al. 2003), lower education levels, and limited economic resources for investing in disease prevention (Ali et al. 2017; de Andrade et al. 2015; Szwarcwald et al. 2005). In addition, they exhibit lower levels of medical self-efficacy (Joventino et al. 2013; Oriá et al. 2009) and more traditional gender ideologies (Baldwin and DeSouza 2001; Pulerwitz and Barker 2008) than more-affluent populations. These differences potentially contribute to differences in disease and pregnancy prevention as well as in accessing key scientific information to navigate a new health threat, such as ZIKV.

Another key aspect in birth patterns in Brazil is a set of two well-documented peaks, in March–May and in September, with no significant seasonal variation across educational levels or regions (Moreira 2013). Seasonality in births is commonly reported in all human populations, and the pattern is resistant to change over time (Cummings 2014), suggesting the need to account for context-specific seasonality.

Conceptual Framing

Past studies have documented fertility changes as a consequence of uncertainty brought about by external shocks, such as economic crisis (Sobotka et al. 2011; Vrachnis et al. 2014), public health emergencies (Trinitapoli and Yeatman 2011), wars (Agadjanian and Prata 2002), and natural disasters (Behrman and Weitzman 2016; Finlay 2009; Nobles et al. 2015). In times of uncertainty and increased risk, physical and social exposure to a perceived threat should trigger reevaluations of reproductive intentions, resulting in behavioral changes that affect reproductive outcomes, such as live births and fertility (Trinitapoli and Yeatman 2011). Because ZIKV involves a *direct* threat to fetuses, the epidemic likely has consequences for live births and, potentially, for fertility.

According to Bongaarts' (1978) proximate determinants of fertility, fertility is determined directly by reproductive behaviors and indirectly by factors that influence women's options and the opportunity costs associated with them, such as SES and physical location. In the context of a major threat, such as an epidemic, this theory suggests that at least some women likely develop strategies to diminish their risk of infection and/or of full-term pregnancy (Johnson-Hanks 2004, 2006; Sobotka et al. 2011; Trinitapoli and Yeatman 2011; Vrachnis et al. 2014). However, the type of strategies they devise—and whether they are able to implement them—likely vary with sociodemographic contexts and exposure to the threat. The literature also suggests that these effects are likely moderated by SES because of differences in material constraints and corresponding outlooks that also play a role in overall pregnancy prevention.

Unlike past health threats or unwanted pregnancy, the ZIKV epidemic brings a new set of variables into childbearing decision-making. ZIKV might pose serious threats to adult well-being, such as Guillain-Barré syndrome, but the risks to fetuses are more frequent and in most cases are more severe than those faced by adults (Araújo et al. 2017; Hoen et al. 2018; Mier-y-Teran-Romero et al. 2018). Newborns are confronted with the prospect of congenital defects, including brain abnormalities, and no chance of cure (Lin et al. 2017). The ZIKV epidemic also differs from past health shocks, such as the HIV and AIDS epidemic, because ZIKV is transmitted *both* sexually and via mosquitos. Further, the mosquito is familiar to Brazilians, which may have created a sense of trivialization of the virus at first. For several decades, Brazil has been infested by the mosquito *Aedes aegypti*, resulting in high incidence of dengue fever (Siqueira et al. 2004). This infestation led to widespread public health campaigns aimed at teaching the population how to prevent mosquito breeding (i.e., avoiding stalled water and open sewage). Such familiarity with the transmitting mosquito might have led the population to initially disregard ZIKV as a serious threat. When the message about the danger of the virus for fetuses was disseminated with the announcement of the link between ZIKV and microcephaly (via public health campaigns, media, and medical knowledge), individuals may have begun to recognize the potential severity of infection and subsequently adjusted their behavior to avoid pregnancy (Guedes et al. 2018).

Equally important to consider, ZIKV was spatially variegated. That is, it was first detected in northeast Brazil (Diniz 2016; Pan American Health Organization 2015a; Zanluca et al. 2015); moreover, states in this region were hit hardest by the epidemic (Brasil 2017; de Oliveira et al. 2017a, b). For instance, in 2015, microcephaly cases in the state of Pernambuco alone (in the northeast) constituted 38.76% of all notified cases in Brazil (Brasil 2016). In contrast, microcephaly cases in all southern and southeast states together represented only 5.37% in the same year (Brasil 2016). Because of differences in the onset and severity of the epidemic, we examine two states in each of these two regions, where contrasts were highest: Pernambuco (PE) and Rio Grande do Norte (RN) in the northeast, and Santa Catarina (SC) and Paraná (PR) in the south. Our regionally paired states are socioeconomically and demographically similar; at the same time, the epidemic affected them in somewhat different ways (de Oliveira et al. 2017b). In PE, cases of ZIKV were reported early on, and rates increased rapidly (de Oliveira et al. 2017b). The state of RN had comparatively lower levels of ZIKV incidence than the state of PE in 2015 and 2016. SC reported minimal incidence levels of both ZIKV and microcephaly/CZS throughout the entire epidemic, but PR reported comparatively higher levels of ZIKV incidence in 2016. Regarding CZS and microcephaly, PE had high levels of CZS and microcephaly in 2015 and 2016, but RN had high levels of microcephaly and CZS incidence in only 2015 (de Oliveira et al. 2017b). SC had minimal incidence levels of both ZIKV and microcephaly/CZS throughout the entire epidemic; PR had high levels of ZIKV incidence in 2016 and minimal levels of microcephaly/CZS in both periods (de Oliveira et al. 2017b). Following these general trends, we would expect greater and earlier declines in the northeastern states (PE and RN) relative to the southern states (SC and PR). Within the northeast, we expect the greatest and earliest declines in PE; within the south, we expect the greatest and earliest declines in PR.

Data

We draw from three sources of data to compile five data sets. First, from the Sistema de Informação de Nascidos Vivos (Live Births Information System), SINASC (Ministério da Saúde 2019), we obtain number of live births by month and year, and by mother's educational level. SINASC is a national database of administrative records that gathers information on live births under the jurisdiction of Brazil's Ministry of Health. The SINASC data, with overall underreporting estimated at less than 4% (Ministério da Saúde 2017; Szwarcwald et al. 2014), has been used extensively (i.e., Castro et al. 2018).

Second, from the population projections estimated by the Center for Development and Regional Planning (Centro de Desenvolvimento e Planejamento Regional) (Cedeplar 2014), we obtain (1) number of women at reproductive ages by *state* and *national* levels by month and year, (2) number of women at reproductive ages and population size by *municipality* by month and year, and (3) age-specific fertility rates by year.

Third, from the nationally representative Pesquisa Nacional de Amostra de Domicílio (National Household Sample Survey), PNAD (IBGE 2019), we obtain the number of women at reproductive ages by level of education by year. Because Brazil's Census Bureau does not provide the five-year age group population by education in intercensal years, we use the PNAD to derive the educational structure and estimate the denominators of the fertility rates by educational levels.[6] The high quality of the PNAD data has been widely documented (i.e., Lam and Duryea 1999; Marteleto and Souza 2012).

Finally, we also use monthly data on the size of the population at childbearing ages (15–49) of each municipality as the denominator in a series of Poisson models, as described shortly. This information comes from projections[7] of monthly numbers of women of childbearing ages by municipality. To get to our final analytical sample, we merge data on live births from SINASC and population projections on 5,565 municipalities[8] by month and year, from 2014 to 2016.

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[6] Projections of women at childbearing ages by educational levels are not widely available for Brazil, so we apply the educational structure from the nationally representative PNAD (1995 to 1999, 2001 to 2009, and 2011 to 2016) to projections to estimate the number of women by levels of education (IBGE 2019). We interpolate monthly data from the yearly trend using a nonstochastic exponential interpolation method. Then we calculate the proportions for each interpolated number of women at each five-year age group by month-year and education level and use these proportions to obtain the expected numbers using the Cedeplar totals.

[7] Brazil's Census Bureau does not make municipal projections available. Thus, we use projections estimated by Cedeplar based on 2010 census data. The overall number of women at childbearing ages is estimated using a combination of small-area estimation procedures, multiregional migration tables, and other standard projection techniques adjusted by expert opinion on the future behavior of each demographic component (Cedeplar 2014).

[8] We eliminate five municipalities out of the 5.570 total number of Brazilian municipalities because they were created after 2010 and therefore do not have corresponding population projections data estimated using the 2010 census. We aggregate localities in the outskirts of Brasília as a single entity; this is usual practice regarding the federal district.

Methods

Pre- and Post-ZIKV Epidemic Trends in Live Births and Fertility Rates

We examine monthly data from SINASC[9], [10] (Ministério da Saúde 2019) to show trends in live births for the 2014–2016 period for the entire country and for four selected states in two distinct regions—Pernambuco (PE) and Rio Grande do Norte (RN) in the northeast, and Santa Catarina (SC) and Paraná (PR) in the south. We also calculate yearly percentage change in live births by month (2014 to 2015 and 2015 to 2016) during the ZIKV epidemic.

We estimate age-specific fertility rates (ASFR) and total fertility rates (TFR) for the entire country under two scenarios. In the *observed* scenario, we use the number of live births observed in SINASC data between 2015–2016 (Ministério da Saúde 2019). In the *expected* scenario, we use the number of live births between 2015–2016 if fertility rates were estimated according to projected fertility, mortality, and migration schedules (Cedeplar 2014). We use the the projected number of females by age group as the denominator.[11] These *expected* rates reflect what the ASFRs would have been in 2016 if fertility behavior followed the expected pattern projected in the absence of the ZIKV epidemic.

We estimate TFR for the scenarios of the ASFRs given that the calculation represents a hypothetical average number of children a woman would have at the end of her reproductive life if she were to experience the set of current ASFRs through her lifetime, and were to survive at least until the end of her reproductive years (Preston et al. 2001). We also examine trends in live births and estimate ASFRs by mother's educational level,[12] grouped as low (0–8 years of schooling), medium (9–11 years), and high (12 or more years).

We estimate general fertility rates (GFRs)[13] for the entire country and for each state. The goal is to account for the possibility that observed trends in live births can be an artifact of

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[9] Administrative reports and vital statistics information on live births in developing countries typically face data quality issues, including delay in registration, misreporting, and undercounting. For 2014, undercount at the national level was 4% (Ministério da Saúde 2017).

[10] Live birth data sets were transferred directly from the SINASC website as updated information became available (May 5, 2017; July 29, 2017; March 20, 2018; and April 28, 2018, when 2016 data became final). Finally, on March 21, 2019, we retrieved the whole data set once again.

[11] We also estimate fertility rates using as denominator projections by the Brazilian Census Bureau (IBGE 2013) to assure results held regardless of the denominator used (not shown but available upon request). We estimate the observed fertility rates using direct methods and the expected fertility rates by indirect methods, using the census.

[12] We use maternal education as a measure of SES for conceptual and methodological reasons. Conceptually, maternal education is the strongest socioeconomic predictor of live births and fertility in Brazil (Cavenaghi and Berquó 2014; Rios-Neto et al. 2018); it is a more stable measure than income and has been used extensively as the major proxy for SES in Brazil (Lam and Duryea 1999; Marteleto and Dondero 2013; Potter et al. 2010). Methodologically, the data set we use offers two variables that reflect SES: maternal education and maternal occupation. Information on income is not collected. Information on maternal occupation is collected but not made available for public use. Maternal education is thus the only proxy available to us. Fortunately, it is missing in only 1.3% to 2.3% of cases, depending on the year.

[13] The GFR is the ratio between the number of live births and the number of person-years lived by females aged 15–49 years (Preston et al. 2001). Because the GFR depends on the proportion of person-years lived by females aged 15–49 years, the rates are sensible to compositional differences in the age structure of reproductive-aged women. As such, the GFR could potentially change over time simply because of changes in the proportion of women at childbearing age, not because of actual changes in birth patterns. This is an undesirable property of the GFR and the main reason it is seldom used. We estimate GFRs as a counterfactual exercise to predict the expected number of births to highlight the very effect that a changing age structure of women at childbearing ages would have been on the number of live births. We use the GFR's limitation— its sensitivity to the age structure of women ages 15–49—as a resource to compare *actual* with *expected* live births. This is a way to tease out whether the change in the number of live births we document could have been the result of a change in age structure. Because the counterfactuals rely on the number of women at childbearing ages from 2010, prior to the ZIKV epidemic, our exercise shows the contribution of changes in age structure only to the GFR. The difference in

past fertility behaviors. That is, a declining number of women of reproductive age due to population momentum could drive a decline in the number of births (Preston et al. 2001).

Poisson Fixed-Effects Analysis

We next use monthly data by municipality from January 2014 to December 2016 to estimate live birth rates following a conditional Poisson process accounting for exposure as the number of women at reproductive ages in each municipality (Rabe-Hesketh and Skrondal 2012). The number of live births in month-year in municipality is:

$$\ln\left(\boldsymbol{\mu}_{m_y j}\right) = \mathbf{X}_{m_y j}\boldsymbol{\beta} + \mathbf{Z}_j \alpha_j + 1 \times \ln\left(\boldsymbol{W}_{m_y j}\right), \tag{1}$$

Where $\mathbf{X}_{m_y j}$, $\boldsymbol{\beta}$, and $\boldsymbol{\alpha_j}$ are the vectors of time trend indicators, coefficients for observed trends, and the municipality-specific effects of their $\boldsymbol{Z_j}$ time-invariant attributes, respectively. The term $\boldsymbol{W}_{m_y j}$ represents the number of women at reproductive ages by month-year and municipality, and works as an exposure variable.

Under this formulation, the exponentiated coefficients can be interpreted as ratios of expected counts. As components of $\mathbf{X}_{m_y j}$, we use dummy variables representing years 2014 and 2015 (2016 as reference) and dummy variables for each month from July through December (with January to June as reference). We use month dummy variables because they allow us to test whether year differences in live birth rates for each month increased when compared with the same difference for the following months (August to December). We group the months of January–June 2016 as the ommitted category to follow the trend in live births (discussed earlier) in Fig. 1. The second test evaluates if the decline in GFR observed in 2016 (accelerated from July to December with at a growing rate) is statistically different from the trend observed in 2015. We cluster the standard errors at the municipality level and account for heteroskedastic-robust errors in final model estimates. As sensitivity analysis, we also estimate the same models through double fixed effects. In the double fixed-effects models, both the effects of municipality characteristics that are time-invariant and commonalities across municipalities that are shared in the same period are ruled out, reducing omission bias from these unobserved attributes.

Results

National Analysis: Trends in Live Births and Fertility Rates

We begin by graphing the observed monthly absolute number of live births in the period 2014–2016 (lines) and the yearly percentage change in live births for the 2014–2015 and 2015–2016 periods (bars) in Fig. 1. Although the lines corresponding to 2014 and 2015 portray a very similar pattern, the line representing 2016 reveals a marked departure. A clear decline emerges around July and August, approximately nine months after Brazil's Ministry of Health amply publicized the link between ZIKV and microcephaly. The bars representing the annual percentage change from 2014–2015 show a slight increase in live births in this

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estimation and the sign of the difference (positive or negative) provide a sense of the magnitude of live births that would have increased/decreased as a result of the aging structure of women at childbearing ages.

period. The 2015–2016 annual percentage change for each month in Fig. 1 shows a clear decline in live births in 2016 starting in July 2016 and accelerating in September 2016.

One possibility is that the declining trends in Fig. 1 could be the result of a potential decline in the absolute number of women at childbearing ages. To test this, we estimate expected and observed GFRs for the entire country. Panel A of Table 1 shows that although the number of births estimated from 2010 to 2016 decreased by 0.14% and by 5.30% from 2015 to 2016 (column 1), the proportion of females at childbearing ages increased by 4.82% from 2010 to 2016 and by 0.56% from 2015 to 2016 (column 2). In other words, previous higher fertility schedules continue to contribute to demographic inertia, with the total number of women at reproductive ages increasing despite negative growth rates among younger age groups. Thus, the expected number of births would follow the same proportion had the GFR remained at the 2010 level until 2016: the expected number of births in Brazil in 2016 would have been 0.56% higher than 2015 and 4.82% higher than 2010 levels because of the increase in the total number of women at childbearing ages. Brazil would have experienced 141,913 additional births if the fertility structure remained constant at the levels observed in 2010.[14] Demographic inertia and the echoes of past higher fertility schedules should thus be contributing to increasing rather than decreasing numbers of births.

Having ruled out the possibility of compositional changes driving the observed trends in live births, we next turn our attention to ASFRs. Figure 2 graphs four ASFRs. Solid lines represent the expected fertility schedule (or age structure) with assumptions made before the ZIKV epidemic in both the numerator and the denominator. Dashed lines are based on the observed data on live births in the numerator and the projected number of women at childbearing ages in the denominator.

Figure 2 portrays a pattern in which the largest differences between *observed* and *expected* fertility rates occur among younger women, the group with the largest fecundity window. We calculate *observed* TFRs for Brazil at 1.77 in 2015 and 1.68 in 2016, a 5.38% change. The TFRs under the *expected scenarios* are 1.72 for 2015 and 1.70 for 2016, yielding a positive variation in fertility of 2.76% in 2015 and a negative variation in fertility of 1.62% in 2016. The analysis presents a decline in *observed* fertility from 1.77 to 1.68 when we compare *observed* TFRs over time (−5.21%). The analysis also presents a decline in 2016, from 1.70 to 1.68, when we consider the *expected* TFR if fertility assumptions held true and calculate the TFR with the *observed* number of live births (−1.62%).

Figure 3 is analogous to Fig. 1 but shows trends in live births by women's educational level. Figure 3 suggests clear differences in live birth trends for low- versus medium- and high-educated women. The bars corresponding to the percentage change in live births from 2014 to 2015 in Fig. 3 show a decline in live births among low-educated women and slight increases among high-educated women. The declining trend already in course among low-educated women accelerates starting in mid-2016. For high-educated women, on the other

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[14] This decline in the observed number of live births we examine is not due to compositional effects in the number of females at childbearing ages, suggesting that we cannot infer that the observed decline and the timing of decline in births are attributable to population composition effects.

hand, the 2015 trend of modest increase in live births turns sharply into solid declines around mid-2016.

Figure 4 shows ASFRs analogous to Fig. 2 but shows these rates separately by maternal education. Unsurprisingly, the differences in ASFR trends across educational levels found before the ZIKV epidemic persist. The ASFR curves peak at ages 20–24 for low-educated women and at ages 30–34 for high-educated women. Findings from Fig. 4 also show clear 2015–2016 declines in ASFRs across all educational groups and age groups up to 35–39.[15]

Table 2 shows the percentage change in ASFRs using the estimates shown in Fig. 4. The percentage change in ASFRs was higher among younger *vis-à-vis* older women. However, high-educated women experienced the largest percentage decline in TFR (6.98%) of all three educational groups, although very similar to the decline of low-educated women (6.54%). Interestingly, the decline experienced by low-educated women is spread along all the reproductive ages, a trend that was already in place before the epidemic. The decline among high-educated women is concentrated among the early reproductive ages, when women have a wide reproductive window ahead, with time to adjust their fertility behavior to meet their ideal family size.

State Analysis

Trends in Live Births—Figure 5 is analogous to Fig. 1 but presents live births in the states of PE and RN in the northeast and SC and PR in the south for 2014–2016. Although the lines corresponding to 2014 and 2015 portray a very similar pattern, the lines representing 2016 show a marked departure from the two previous years in all states, with differences in the month and magnitude of the declines. A sharp decline emerges in July in PE and RN, approximately eight to nine months after the link between ZIKV and microcephaly was suggested. In the southern states, declines emerged later, in October (SC) and in December (PR). Remarkably, the percentage of change/decline in live births in PE reached the highest level of 23%; highest levels in the other states were 16% in RN and only 8% and 10% in SC and PR, respectively.

Panel B in Table 1 shows that the number of females at reproductive ages increased from 2010 to 2016 and from 2015 to 2016 in all four states (column 2). A consequence of the increasing numbers of women at reproductive ages is an increase in the *expected* number of live births in all four states (column 4). Contrary to this *expected* tendency in live births and similar to the observed national pattern, the *observed* number of births from 2015 to 2016 decreased in all states (column 1). Comparing the number of *expected* births had the fertility structure remained the same as 2010 (column 4) with the number of *observed* births in 2016 (column 1), we find that the observed numbers of births is smaller than the expected in the northest (PE and RN) (column 6). In the southern states of SC and PR, the *observed* number of births is still larger than the *expected* number of births in the 2010–2016 period, possibly due to population momentum and a large number of women in age groups with high fertility

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[15] Fertility levels are slightly similar across educational groups for older age groups in Brazil (Camarano 2014), but fertility might be qualitatively different for low- versus high-educated according to birth order, as the pattern of first births is highly dependent of mother's education; high-educated women are having the highest first birth intensity around age 32 while low-educated women have their highest first birth intensity around ages 18–21 (Lima et al. 2018).

levels within the reproductive age span. Interestingly, in the 2015–2016 period, we observe a decline in observed births in the southern states. These findings suggest that the ZIKV epidemic counterbalanced the 2010–2016 expected tendency of increasing births. Importantly, all Brazil's states present fewer live births in 2016 than in 2015. We show GFRs for all Brazilian states in Table A1 in the online appendix. This table is similar to Table 1, but columns 2, 3, and 4 are ommited.

Figure 6 is analogous to Figs. 1 and 3, showing trends in live births by educational level but also by state. In all four states, the 2014–2015 pre-epidemic live births trend is characterized by declines among low-educated women and by increases among high-educated women. The 2015–2016 trend reveals steeper declines among low-educated women than those of the previous period. The trends among high-educated women are remarkable, with large declines that mark a reversal from the previous period. Equally interesting, this reversal trend on live births among high-educated women holds for all states except for SC, which had modest incidence rates of ZIKV and microcephally during the national epidemic.

Municipality Poisson Fixed-Effects Results—We next examine the declines in live births documented earlier for the national and state levels while isolating all fixed and unobservable characteristics of municipalities. The goal is to determine whether these patterns hold and whether the timing of the declines in live births varies across selected states. Table 3 shows the coefficients of Poisson fixed-effects models, with live birth rates as the dependent variable. Each column showing the results of Poisson models is followed by a corresponding column showing the results of double fixed-effects models estimated as sensitivity analysis. The results are similar to the Poisson specification in that the trend in declining live births holds even with the more restricted double fixed-effects approach.

Panels A and B of Table 4 show chi-square estimates based on the Poisson models of Table 3. Columns 1 and 2 show results for the entire country, and columns 3–10 show results for our four selected states. Panel A in Table 4 shows chi-squares estimates testing the significance of the yearly differences (2015 vs. 2016) in coefficients for each month after July 2016. We combine the January–July 2016 period to reflect the descriptive analysis above that indicates a decline in live births starting in August 2016. With the exception of October in SC, all the chi-square estimates in panel A are statistically significant at the .01 level or lower, suggesting that 2016 live births are statistically different from their corresponding month in 2015. This is true nationally and for each state we examine. Panel B shows chi-square estimates testing whether the yearly differences (yearly deltas) accelerate in each month. The chi-square estimates are statistically significant in different months across states, suggesting that the gap estimated in panel A accelerates for the first time in different months, depending on the state. The first time the gap in yearly rates is significant at the .01 level is in August for PE and in September for RN. In the southern states, however, the gap accelerates in October for PR.

Sensitivity Tests—We conduct two sensitivity tests for further empirical support, in addition to the double fixed-effects models reported earlier. The first sensitivity analysis focuses on three analytical samples defined by population size: municipalities with up to 20,000 inhabitants, up to 50,000 inhabitants, and more than 50,000 inhabitants (Tables B1A and B1B, online appendix). This eliminates potential noise resulting from small numbers of live births in small municipalities. Results of chi-square tests follow the same trend in all three municipality groups, with the exception that the decline in live births starts to accelerate in September in small municipalities, whereas the gap accelerates in August in the largest municipalities.

We also conduct a comparative analysis of each of Brazil's regions to determine regional patterns (Tables B2A and B2B, online appendix). The northeast and southeast mimicked the national trend, with declines accelerating in August. In the south, the decline in live births accelerated in September; and in the center-west and north regions, the decline represents an unstable behavior and should not be interpreted as a trend.

Conclusions and Discussion

In this article, we aim to provide one of the first analyses of live births and fertility trends during the ZIKV epidemic in Brazil, the country most affected by the 2014–2016 epidemic. Any country with a history of ZIKV transmission "has the potential for re-emergence or re-introduction" (World Health Organization 2019:1), which indicates that ZIKV and its associated neurological complications continue to represent a global public health challenge. The vast majority of existing research has focused on clinical, immunological, or epidemiological aspects of ZIKV, with scant attention to its reproductive consequences. However, understanding the reproductive consequences of ZIKV is key because of its substantial implications for live births, fertility, and women's health.

This analysis offers evidence of a national decline in live births starting around mid-2016, approximately nine months after the link between ZIKV and microcephaly was suggested and when public officials advised women against pregnancy during the epidemic. The general decline cannot be explained by population compositional effects.

We find important nuances to the overall decline in live births. First, given that Brazil's high levels of social inequality have had important implications for women's birth and fertility patterns prior to the ZIKV epidemic, we expected the effects of the epidemic also to vary along socioeconomic lines. We find declines in live births for women of all educational levels. However, our findings suggest that the 2015–2016 downward trend in live births was a sharp change from the previous year's upward trend in live births among high-educated women. At least for this group of women, the uncertainty and risk of a newborn with microcephaly or other CZS brought about by the ZIKV epidemic triggered childbearing reevaluations (Johnson-Hanks 2004; 2006 Sobotka et al. 2011; Vrachnis et al 2014). All women, regardless of educational level, were aware of the risk of ZIKV for fetuses (Marteleto et al. 2017) and seemed to have diminished their risk of full-term pregnancy. The precise mechanism driving these declines, however, remains unclear because we lack the necessary data to confirm the roles of abortion and contraceptive use in averting births during the epidemics. High-educated women in Brazil have high access to safe and clinical abortion (Diniz and Medeiros 2010; Martins-Melo et al. 2014; Menezes and Aquino 2009) and to contraceptive methods (Borges et al. 2016; Coutinho 2016; Farias et al. 2016; Nascimento et al. 2017), and these women were also less likely to be infected with Zika (Ali et al. 2017), which suggests that abortion and contraception could have impacted live births and fertility. In times of change brought about by a new disease, access to reliable information—which is also stratified along education lines—is also key in determining action.

A second important nuance to the general findings of decline in live births is that the decline was larger in Brazil’s northeast, particularly in PE—where the Zika epidemic first started and where the microcephaly epidemic was most severe—than in the south. This suggests that the timing of the onset and severity of the epidemic was important in determining its consequences for live births and that higher social exposure to the virus might have exacerbated women’s desires and actions to prevent pregnancy or to have an abortion. This interpretation is in line with past research showing that the level of exposure to a threat is key in determining the extent of its consequences for childbearing (Agadjanian and Prata 2002; Behrman and Weitzman 2016; Nobles et al. 2015), and with working research suggesting that birth declines aligned with mosquito infestation (Rangel et al. forthcoming). At the same time, we recognize that the southern states exhibited low levels of fertility before the ZIKV epidemic. A next step in further elucidating the role of the ZIKV epidemic onset on live births is to directly account for how the timing and proportion of confirmed cases of microcephaly across Brazil’s large territory is associated with fertility.

Further analyses focusing on fertility suggest a slight decline in the TFR. The TFRs were slightly lower in 2016 than in 2015. They were also slightly lower than the TFRs expected for 2016 had trends not been sensitive to the ZIKV epidemic. Our findings regarding the slight overall impact of the ZIKV epidemic on the TFRs are in line with previous studies examining other shocks to fertility in that TFRs are affected by only a few points, and these effects tend to be short-lived as they influence the tempo of fertility, rarely leaving an imprint on cohort fertility levels (Sobotka et al. 2011). Marteleto et al. (2017) and Castro et al. (2018) also provided speculations for the course of the overall fertility decline during the ZIKV epidemic. Nonetheless, these studies did not account for the potential contribution of changing age structure, nor did they estimate ASFRs or fertility rates by SES. To the best of our knowledge, ours is the first study to estimate ASFRs throughout the ZIKV epidemic, thus showing that ASFRs dropped at higher rates for younger women than for older women throughout the epidemic. Most of the young women for whom we observe the strongest declines in ASFRs will still have time to catch up on their childbearing if they return to their original projected path, similar to the effect of other shocks (Sobotka et al. 2011). We thus speculate that the relatively small decline in ASFRs we observe is likely to be short-lived and will influence the timing of childbearing mostly through a tempo effect, ultimately not affecting cohort fertility levels (quantum effect). Data from 2017 (not shown) point to the number of births returning to pre- epidemic levels, with marked differences across states. Additional studies using final data from 2017 and beyond will help elucidate this trend.

Our findings show that age and education work together as key factors in how the ZIKV epidemic influenced fertility. Declines in ASFRs were larger among those with high educational levels than for any other group. We speculate that high-educated women acted quickly on their greater access to contraceptive use and safe abortion based on the fact that they still had a wide reproductive age window, a sense of control over their childbearing

(Marteleto et al. 2017), and the means to do so. Equally important, particularly younger women with higher levels of schooling seem to have also been efficient in adjusting their childbearing intentions. It is therefore important to investigate whether the ZIKV epidemic left an imprint in the reproductive behaviors of younger cohorts of Brazilian women—those who experienced the effects of the ZIKV epidemic early on in their childbearing ages—compared with women who were already in their final reproductive years.

In discussing our findings, it is important to note that the ZIKV epidemic may not explain the entire decline in overall live births or in ASFRs for the young high-educated women we observe. For instance, the ZIKV epidemic coincided with an ongoing economic and political crisis in Brazil. This crisis may have also influenced declines in live births and fertility rates (Sobotka et al. 2011; Vrachnis et al. 2014). One way that we address the potential confounding effect of macro-social and economic effects is through municipality fixed-effects models that account for municipality factors. Our findings from these models using monthly data for each municipality suggest a significant decline in live births around nine months after the suggestion of the ZIKV-microcephaly link when birth seasonality and the size of the female population at childbearing ages (live birth rates) are controlled for. Importantly, because our models also isolate for characteristics shared by all individuals living in each municipality, they account for macro-social and economic conditions at the municipality level. Sensitivity analyses show that these results hold in double fixed-effects models—that is, even when both invariant and variant municipality factors are isolated.

Further findings show that the trend of declining live birth rates intensifies around mid-2016, with an acceleration of the decline stable to several other model specifications, taking place earlier in the northeastern states than in the southern states. This confirms that the negative trend deepened at around nine months after the link between ZIKV and microcephaly/CZS was announced (Brasil 2015c), suggesting that efficient and consistent use of contraception was likely the main mechanism behind the trend.

A unique feature of the ZIKV epidemic was that its most threatening consequence centered on pregnancy and births. Looking ahead, it will be important to understand the long-term impacts of the epidemic for Brazil and other places ZIKV has touched. We cannot yet assess whether the declines in live births and young ASFRs we observed definetely translate into smaller completed family sizes or reflect only a change in fertility timing. Equally interesting will be to examine the extent to which family sizes differ markedly by the age across women's reproductive years the epidemic hit. Our study also documents declines in live births that are stratified by education and geographic region, raising questions regarding the proximate and distal determinants behind such disparities. Answers to these questions will emerge as additional data on live births becomes available and as further data are collected.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

This research was funded by grant R01HD091257, Reproductive Responses to the Zika Virus Epidemic in Brazil, awarded to PI L. J. Marteleto by the Eunice Kennedy Shriver National Institute of Child Health and Human Development. This research was also supported by grant P2CHD042849, Population Research Center, awarded to the PRC at The University of Texas at Austin by the Eunice Kennedy Shriver National Institute of Child Health and Human Development and Grants 431872/2016-3, 314392/2018-1 and CSA-APQ-01553-16 awarded to Gilvan Guedes by the Brazilian Technological and Scientific Development Council (CNPq) and by the Minas Gerais Research Foundation (FAPEMIG). The content is solely the responsibility of the authors and does not necessarily represent the official views of the NIH or the CNPq. Raquel Z. Coutinho gratefully acknowledges support from the Universidade Federal de Minas Gerais (Edital 11/2017 - ADRC - Programa Institucional de Auxílio à Pesquisa de Docentes Recém-Contratados ou Recém-Doutorados da UFMG). The authors thank Júlia Almeida Calazans, John Casterline, Suzana Cavenaghi, Diane Coffey, Samantha Haussmann, Ana Maria Hermeto C. De Oliveira, Kristine Hopkins, Bernardo Lanza, Vanessa di Lego, Sandra Valongueiro, Joe Potter, Laura Wong, the anonymous reviewers, and Editors for their helpful comments at different stages of this research. We also thank Márcia Castro for discussions on the ZIKV epidemic early on in this research. We also thank the participants of the PRC (UTexas), CCPR (UCLA) and CPC (UNC) brown bags for their helpful suggestions.

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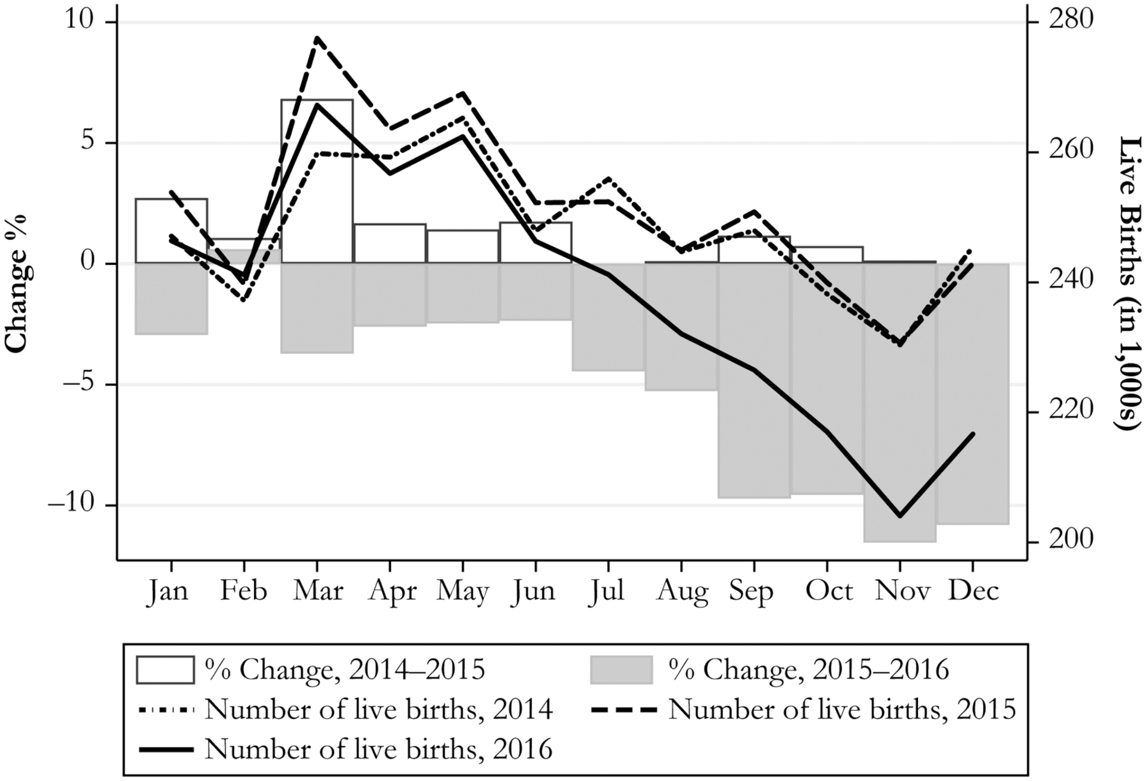

Fig. 1.

Live births and year percentage change by month: Brazil, 2014–2016

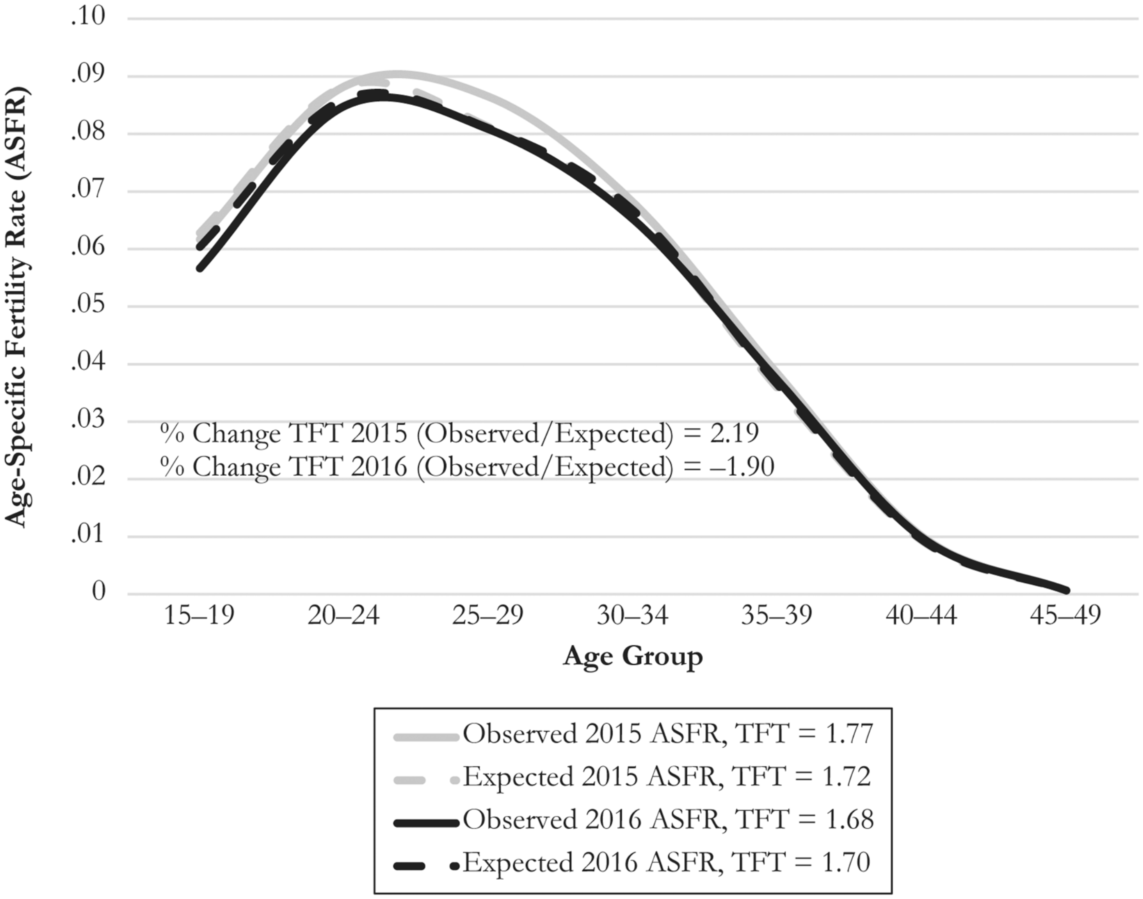

Fig. 2.

Observed and expected age-specific and total fertility rates: Brazil, 2015 and 2016

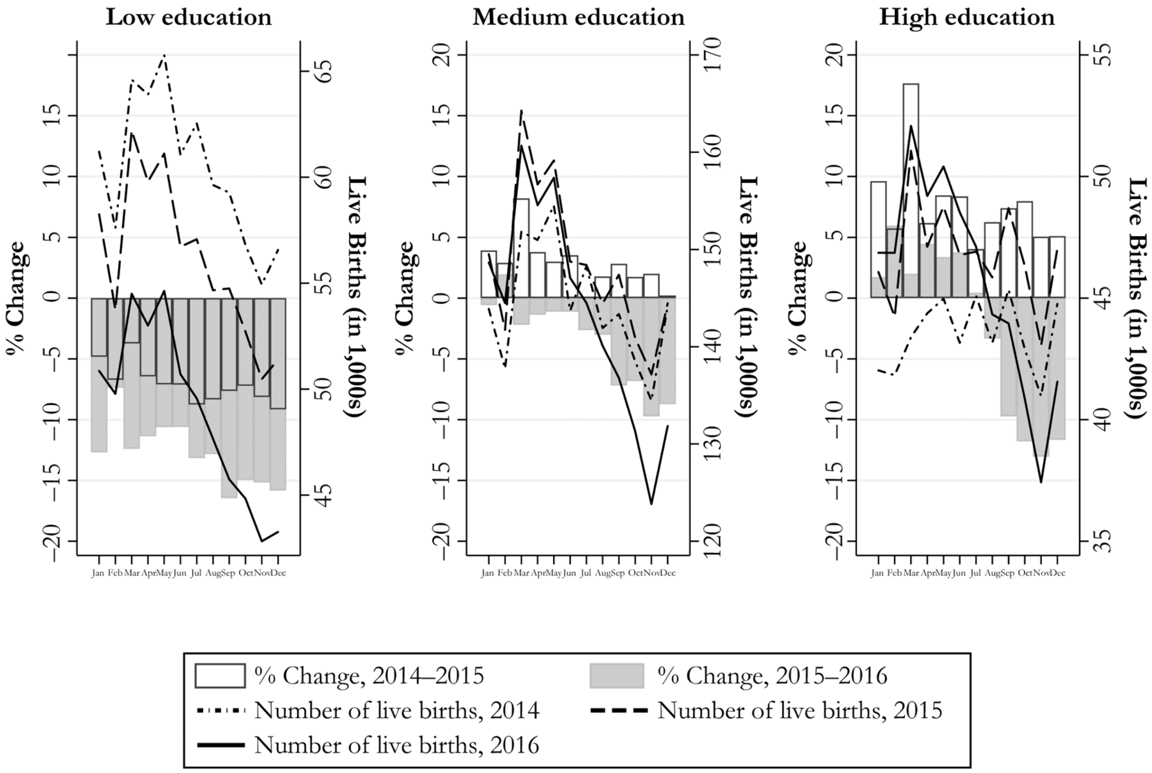

Fig. 3.

Live births and yearly percentage change by month and mother's education: Brazil, 2014–2016

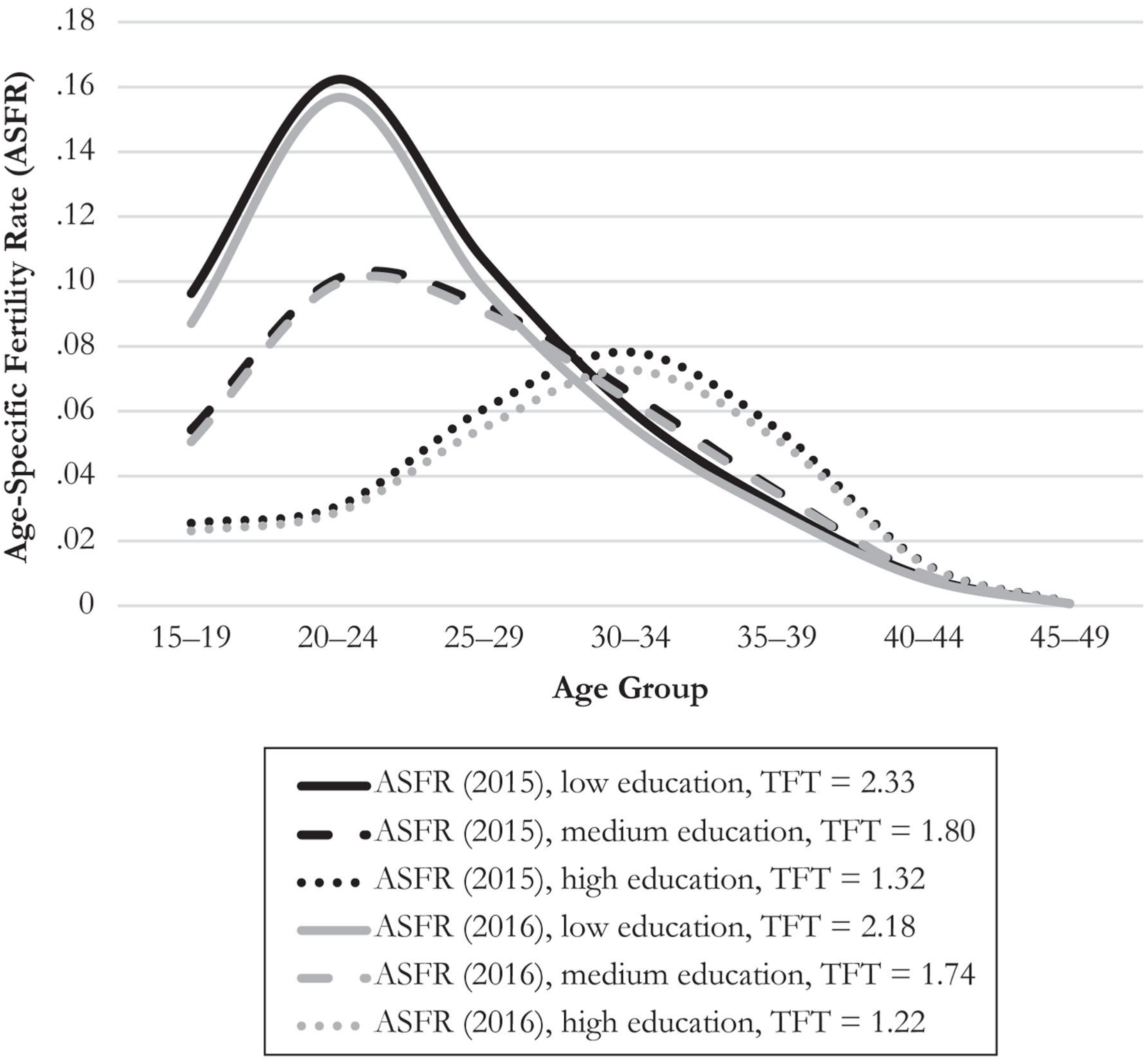

Fig. 4.

Age-specific fertility rates and total fertility rates by mother's education: Brazil, 2015–2016

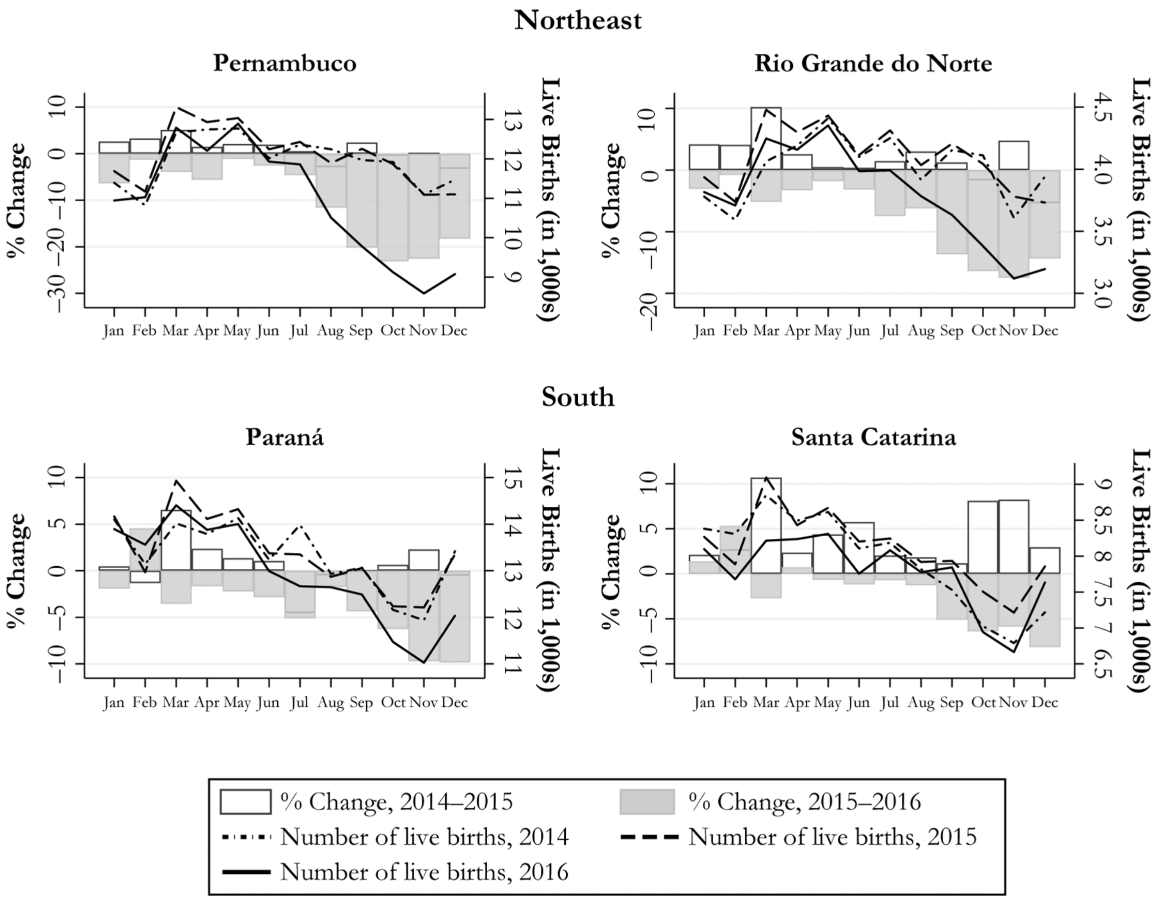

Fig. 5.

Live births and year percentage change by month: Selected states of Brazil, 2014–2016

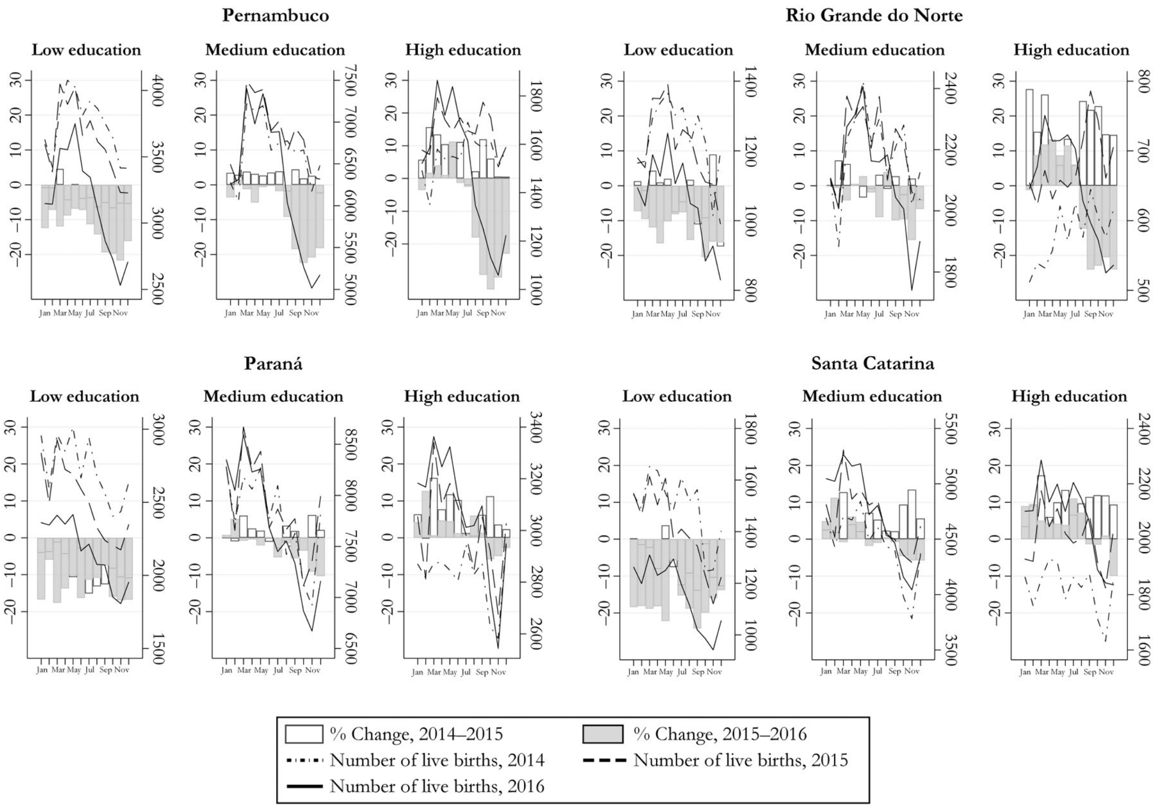

Fig. 6.

Live births and yearly percentage change by mother's education and month: Selected states of Brazil: 2014–2016

Table 1

Relative and absolute differences in estimated and expected live births, GFR: Brazil and selected states, 2010–2016

Year	Observed Live Births (1)	Females Ages (15–49) (2)	GFR (estimated) (3)	Expected Births (GFR 2010) (4)	Relative Difference With 2010, Observed and Expected (%) (5)	Absolute Difference in Expected Births (6)
A. Brazil						
2010	2,861,868	53,793,567	0.0532	2,861,868	0.00	0
2011	2,913,160	54,225,179	0.0537	2,884,830	0.80	28,330
2012	2,905,789	54,668,530	0.0532	2,908,417	1.63	−2,628
2013	2,904,027	55,123,845	0.0527	2,932,640	2.47	−28,613
2014	2,979,259	55,591,356	0.0536	2,957,512	3.34	21,747
2015	3,017,668	56,071,299	0.0538	2,983,045	4.23	34,623
2016	2,857,800	56,384,596	0.0507	2,999,713	4.82	−141,913
%Δ (2015/2016)	−5.30	0.56	—	—	—	—
%Δ (2010/2016)	−0.14	4.82	—	—	—	—
B. Selected State Pernambuco (PE)						
2010	136,591	2,505,261	0.0545	136,591	−95.23	0
2011	140,079	2,523,297	0.0555	137,574	−95.19	2,505
2012	141,382	2,541,462	0.0556	138,565	−95.16	2,817
2013	141,453	2,559,759	0.0553	139,562	−95.12	1,891
2014	143,489	2,578,187	0.0557	140,567	−95.09	2,922
2015	145,024	2,596,748	0.0558	141,579	−95.05	3,445
2016	130,733	2,613,336	0.0500	142,483	−95.02	−11,750
%Δ (2015/2016)	−9.85	0.64	—	—	—	—
%Δ (2010/2016)	−4.29	4.31	—	—	—	—
Rio Grande do						
2010	47,668	905,917	0.0526	47,668	−98.33	0
2011	48,101	915,336	0.0526	48,164	−98.32	−63
2012	46,993	924,853	0.0508	48,664	−98.30	−1,671
2013	46,798	934,469	0.0501	49,170	−98.28	−2,372
2014	48,111	944,185	0.0510	49,682	−98.26	−1,571
2015	49,099	954,002	0.0515	50,198	−98.25	−1,099
2016	45,366	962,205	0.0471	50,630	−98.23	−5,264
%Δ (2015/2016)	−7.60	0.86	—	—	—	—

	Observed Live Births	**Females Ages (15–49)**	**GFR (estimated)**	**Expected Births (GFR 2010)**	**Relative Difference With 2010, Observed and Expected (%)**	**Absolute Difference in Expected Births**
Year	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
%Δ			—	—	—	—
(2010/2016)	−4.83	6.21				
Paraná (PR)						
2010	152,051	2,967,427	0.0512	152,051	0.00	0
2011	152,902	2,974,868	0.0514	152,432	0.25	470
2012	153,945	2,982,328	0.0516	152,815	0.50	1,130
2013	155,758	2,989,806	0.0521	153,198	0.75	2,560
2014	159,915	2,997,303	0.0534	153,582	1.01	6,333
2015	160,947	3,004,819	0.0536	153,967	1.26	6,980
2016	155,066	3,008,871	0.0515	154,175	1.40	891
%Δ			—	—	—	—
(2015/2016)	−3.65	0.13				
%Δ			—	—	—	—
(2010/2016)	1.98	1.40				
Santa Catarina	(SC)					
2010	84,611	1,767,410	0.0479	84,611	0.00	0
2011	87,481	1,790,942	0.0488	85,738	1.33	1,743
2012	88,772	1,814,787	0.0489	86,879	2.68	1,893
2013	89,875	1,838,949	0.0489	88,036	4.05	1,839
2014	93,232	1,863,434	0.0500	89,208	5.43	4,024
2015	97,223	1,888,244	0.0515	90,396	6.84	6,827
2016	95,313	1,902,736	0.0501	91,089	7.66	4,224
%Δ			—	—	—	—
(2015/2016)	−1.96	0.77				
%Δ			—	—	—	
(2010/2016)	12.65	7.66				—

Note: Assuming expected births had the state GFR at each corresponding 2010 level.

Sources: SINASC 2010–2016; Cedeplar 2014.

Table 2

Percentage change in ASFRs and TFRs by age group: Brazil, 2015–2016

	% Change From 2015 to 2016		
Age Group	**Low Education**	**Medium Education**	**High Education**
15–19	−9.29	−6.41	−9.13
20–24	−3.39	−1.43	−5.85
25–29	−8.69	−3.13	−9.98
30–34	−6.79	−2.80	−5.96
35–39	−5.73	−1.49	−5.50
40–44	−8.04	1.39	−3.70
45–49	−9.76	−3.14	−2.72
TFR	−6.53	−2.81	−6.98

Table 3

Coefficients of fixed-effect (FE) Poisson with offset models and double FE models on live birth rates: Brazil and selected states, 2014–2016

	Brazil		Rio Grande do Norte (RN)		Pernambuco	(PE)	Paraná (PR)		Santa Catarina (SC)	
	Poisson FE	Double FE	Poisson FE	Double FE	Poisson FE	Double FE	Poisson FE	Double FE	Poisson FE	Double FE
Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**
Year (base: 2016)										
2014	−0.0158** (0.0012)	−0.2220** (0.0198)	0.0160† (0.0091)	0.2200** (0.0768)	0.0237** (0.0053)	0.0939† (0.0495)	0.0019 (0.0049)	−0.0416 (0.0475)	−0.4730** (0.0064)	−3.1020** (0.1500)
2015	0.0147** (0.0012)	−0.0083 (0.0169)	0.0401** (0.0090)	0.1940* (0.0804)	0.0429** (0.0052)	0.2250** (0.0541)	0.0164** (0.0049)	0.0330 (0.0481)	−0.2520** (0.0063)	−1.3430** (0.1570)
Month (base: January–June)										
July	−0.0446** (0.0022)	—	−0.0161 (0.0171)	—	−0.0107 (0.0099)	—	−0.0853** (0.0095)	—	0.0851** (0.0119)	—
August	−0.0818** (0.0023)	—	−0.0701** (0.0175)	—	−0.1320** (0.0104)	—	−0.0871** (0.0096)	—	0.0715** (0.0122)	—
September	−0.106** (0.0023)	—	−0.1120** (0.0178)	—	−0.2040** (0.0108)	—	−0.0997** (0.0096)	—	0.0642** (0.0124)	—
October	−0.147** (0.0023)	—	−0.1840** (0.0184)	—	−0.2740** (0.0111)	—	−0.1850** (0.0100)	—	0.0229† (0.0128)	—
November	−0.2080** (0.0024)	—	−0.2650** (0.0190)	—	−0.3360** (0.0114)	—	−0.2250** (0.0101)	—	0.0178 (0.0129)	—
December	−0.1470** (0.0023)	—	−0.2420** (0.0188)	—	−0.2810** (0.0111)	—	−0.1370** (0.0098)	—	0.1050** (0.0126)	—
2014 Month/Year Inte action										
July	0.0591** (0.0031)	0.3110** (0.0361)	0.0680** (0.0238)	0.1140 (0.2080)	0.0326* (0.0139)	0.2520* (0.1100)	0.1020** (0.0132)	0.4920** (0.1160)	−0.0300† (0.0170)	0.6720* (0.3280)
August	0.0511** (0.0031)	0.1540** (0.0357)	0.0390 (0.0245)	−0.0461 (0.1900)	0.1440** (0.0143)	0.6980** (0.0970)	0.0257† (0.0134)	−0.0390 (0.1110)	−0.0408* (0.0173)	0.6560* (0.3140)
September	0.0886** (0.0032)	0.4200** (0.0358)	0.1390** (0.0245)	0.5910** (0.1940)	0.1930** (0.0146)	0.8380** (0.1010)	0.0484** (0.0134)	0.1270 (0.1160)	−0.0096 (0.0174)	1.0850** (0.3140)
October	0.0903** (0.0032)	0.4000** (0.0354)	0.2000** (0.0249)	0.7710** (0.1900)	0.2580** (0.0149)	1.0390** (0.1040)	0.0614** (0.0139)	0.2040* (0.1130)	−0.0760** (0.0181)	0.4770 (0.3240)
November	0.1180** (0.0033)	0.4920** (0.0364)	0.1500** (0.0261)	0.3240 (0.2140)	0.2470** (0.0153)	0.7690** (0.1080)	0.0825** (0.0141)	0.2430* (0.1140)	−0.0986** (0.0184)	0.9870** (0.3260)

	Brazil		**Rio Grande do Norte (RN)**		**Pernambuco**	**(PE)**	**Paraná (PR)**		**Santa Catarina (SC)**	
	Poisson FE	**Double FE**	**Poisson FE**	**Double FE**	**Poisson FE**	**Double FE**	**Poisson FE**	**Double FE**	**Poisson FE**	**Double FE**
Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**
December	0.1220^{**} (0.0032	0.5600^{*} (0.0373)	0.2140^{**} (0.0255)	0.5640^{**} (0.1820)	0.2250^{**} (0.0150)	0.9590^{**} (0.1010)	0.1120^{**} (0.0135)	0.4570^{**} (0.1090)	-0.0358^{*} (0.0176)	1.2780^{**} (0.3420)
2015 Month/Year Intel action										
July	0.0182^{**} (0.0031)	0.1350^{**} (0.0365)	0.0474^{*} (0.0237)	$0.3610^{\dagger}$ (0.1830)	0.0111 (0.0139)	0.1040 (0.1160)	0.0384^{**} (0.0133)	0.0982 (0.1140)	-0.0580^{**} (0.0169)	0.4950 (0.3490)
August	0.0256^{**} (0.0031)	0.0552 (0.0372)	0.0336 (0.0244)	0.2040 (0.1830)	0.0874^{**} (0.0144)	0.2480^{*} (0.1210)	0.0032 (0.0134)	−0.1110 (0.1200)	-0.0678^{**} (0.0172)	0.0604 (0.3220)
September	0.0729^{**} (0.0031)	0.3490^{**} (0.0373)	0.1160^{**} (0.0244)	0.5410^{**} (0.2060)	0.1890^{**} (0.0145)	0.8410^{**} (0.1230)	0.0301^{*} (0.0134)	0.1110 (0.1090)	-0.0447^{**} (0.0173)	0.7620^{*} (0.3390)
October	0.0705^{**} (0.0032)	0.3070^{**} (0.0363)	0.1480^{**} (0.0250)	0.7180^{**} (0.1950)	0.2260^{**} (0.0149)	0.8120^{**} (0.1020)	0.0500^{**} (0.0139)	0.1320 (0.0996)	-0.0435^{*} (0.0178)	0.9470^{**} (0.3350)
November	0.0917^{**} (0.0033)	0.3490^{**} (0.0356)	0.1610^{**} (0.0258)	$0.3160^{\dagger}$ (0.1690)	0.2190^{**} (0.0153)	0.5360^{**} (0.1200)	0.0875^{**} (0.0140)	0.2720^{*} (0.1220)	-0.0636^{**} (0.0181)	0.8890^{**} (0.3090)
December	0.0836^{**} (0.0032)	0.3580^{**} (0.0382)	0.1240^{**} (0.0257)	$0.3450^{\dagger}$ (0.1940)	0.1650^{**} (0.0151)	0.6260^{**} (0.1110)	0.0887^{**} (0.0135)	0.3850^{**} (0.1200)	-0.0513^{**} (0.0175)	0.9010^{*} (0.3710)
Number of Observations	199,980	199,980	6,012	6,012	6,660	6,660	14,364	14,364	10,548	10,548
R^2	—	.649	—	.202	—	.446	—	.152	—	.245
Number of Municipalities	5,555		167		185		399		293	

Note: Standard errors are shown in parentheses.

Sources: SINASC 2014–2016; Cedeplar 2014.

$^{\dagger}p < .10$;

$^{*}p < .05$;

$^{**}p < .01$

Table 4

Tests of significance of difference in coefficients and delta from Poisson fixed-effect models: Brazil and selected states, 2015–2016

	Brazil		**Rio Grande do Norte (RN)**		**Pernambuco (PE)**		**Paraná (PR)**		**Santa Catarina (SC)**	
	χ^2 Statistics	***p* Value**	**χ^2 Statistics**	***p* Value**	**χ^2 Statistics**	***p* Value**	**χ^2 Statistics**	***p* Value**	**χ^2 Statistics**	***p* Value**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**
A. 2015/2016										
Difference in Coefficients										
August	461.44	<.001	7.11	.008	90.25	<.001	17.95	<.001	26.25	<.001
September	1,255.77	.001	33.58	<.001	277.16	<.001	36.86	<.001	15.66	<.001
October	1,801.24	<.001	67.61	<.001	423.75	<.001	112.31	<.001	5.48	.019
November	3,245.56	<.001	103.58	<.001	493.01	<.001	192.92	<.001	7.99	.005
December	2,029.14	<.001	77.40	<.001	331.44	<.001	109.12	<.001	31.21	<.001
B. 2015/2016 Gap Accelerated from July to:										
August	46.59	<.001	0.64	.425	44.31	<.001	1.42	.234	0.01	.915
September	311.06	<.001	10.49	.001	152.44	<.001	0.05	.827	0.91	.339
October	546.37	<.001	27.18	<.001	243.98	<.001	15.03	<.001	4.46	.035
November	1,239.88	<.001	47.26	<.001	292.2	<.001	42.51	<.001	2.83	.093
December	644.37	<.001	33.10	<.001	189.68	<.001	13.09	<.001	0.14	.711

Note: The test assumes the general form: b(July/2015) – b(July/2016) < b(Δ/2015) – b(Δ/2015), where Δ = {August, September, October, November, December}.