SPATIO-TEMPORAL TRENDS OF INFANT MORTALITY IN BRAZIL

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INTRODUCTION

Infant mortality in Brazil has declined appreciably in the past decades, with most significant gains observed since the 1970s (IBGE 1999; Simões 2002). Between 1930 and 1970, the infant mortality rate (IMR) for the country declined by 29.2%, but still remained above 100 per 1,000 live births. Between 1970 and 2005, however, IMR was reduced by 79.7%. These gains significantly contributed to increases in the country's life expectancy at birth (Castro 2001), and put Brazil in a favorable position to achieve internationally set goals to reduce mortality among infants. In 1990, the World Summit for Children adopted a target to reduce the 1990 IMR by one third, or to 70 per 1,000, whichever was the greater reduction, by the year 2000 (UNICEF 1990). Brazil registered a 42% decline in IMR between 1990 and 2000, surpassing the set target, and achieving an IMR of 27.6 per 1,000 in 2000. Also, the decline in infant mortality places Brazil among the few countries likely to meet the Millennium Development Goal (MDG) to reduce child mortality by two thirds between 1990 and 2015 (UNICEF 2005).

Nonetheless, with an IMR of 23.5 per 1,000 in 2005, Brazil still lags behind other countries in South America, such as Uruguay (13.1 per 1,000) and Chile (7.2 per 1,000). Most importantly, the overall decline in IMR does not necessarily indicate that inequalities in infant mortality within the country were equally reduced. This is a critical issue for Brazil, since the country has historically ranked high in terms of income concentration worldwide – Brazil ranked 2nd in 1998 (World Bank 1999), and in 1999 it was the country with the highest ratio between the average income of the 20% richer and the 20% poorer, above 30 (Barros, Henriques and Mendonça 2000). Despite recent improvements (Arbix 2007), the Gini Index in 2007 was at 57, placing Brazil as the 11th most unequal country in the world (World Bank 2007).

Regional inequality in Brazil regarding access to services, as well as social and health outcomes has been widely recognized: while the South and Southeast regions regularly report higher income and better socio-economic indicators, the North and Northeast regions often lag behind (Hoffmann 2000; Medici and Agune 1994; Rocha 1998). As a result, IMRs present a distinct clustering pattern across micro-regions, with high rates often concentrated in the Northeast, and low rates in the Southern portion of the country. Despite this pattern, declines in IMR have occurred countrywide. In an ideal scenario, these declines should be accompanied by reductions in inequalities between rich and poor areas. However, the "inverse equity hypothesis" (Victora et al. 2000) postulates that inequalities may temporarily increase or remain unchanged after the introduction of interventions targeted to reduce infant mortality. The increase is expected to hold until richer areas have reached low levels of IMR (with further improvements harder to achieve), and poorer areas achieve wider access to means for promoting policies toward IMR decline (Victora et al. 2000).

In this paper we address the issues discussed above, and aim to investigate spatio-temporal trends in infant mortality in Brazil between 1980 and 2005, utilizing a time series of indirectly estimated IMRs for micro-regions (Simões 1999). Specifically, we have three major goals. First, we appraise the declines in IMR and in inequalities in infant mortality, in light of the "inverse equity hypothesis". Second, we evaluate the presence of clusters of high and low infant mortality in micro-regions, and assess if/how the clustering pattern changed over time and across space. We also investigate the clustering pattern of the relative change in IMR for 5-year periods of time in an effort to examine whether or not the gains were primarily concentrated in specific areas of the country. Third, we construct a multilevel model for change, also known as random coefficients model (Singer and Willett 2002), as an initial attempt to understand how trajectories of IMR decline differ within and between micro-regions in Brazil.

The remainder of this article is divided into 5 sections. The next section provides a brief historical background on socioeconomic, political, and demographic changes in Brazil potentially related to trends in infant mortality. In the second section we describe the data utilized in the analysis. The methods chosen for IMR estimation, evaluation of spatial clustering, assessment of inequalities, and construction of a change model are detailed in the third section. Our findings are summarized in section four, and we conclude with a discussion in the final section.

HISTORICAL BACKGROUND

Gradual declines in infant mortality were observed in Brazil since the early 20th century, but IMR levels remained high until the 1990s, when the country registered, for the first time, an infant mortality lower than 50 per 1,000. Nonetheless, within-variation among administrative regions was substantial, with the Northeast region registering mortality rates 2.6 times higher than the rates recorded in the South region in 1990. Next, we focus on the period post 1930s to review important political, social, economic, and demographic transformations likely to be connected (directly and/or indirectly) with these trends in infant mortality.

The early 1930s are historically linked to the initial industrial expansion in Brazil (Cano 1988), which fostered the growth of the urban labor market, resulting in intense rural-urban migration. In the same decade, studies focusing on hunger and nutrition commenced in Brazil, culminating with the seminal work from Josué de Castro in 1946, who produced the first detailed map of hunger in the country (Castro 1946). During the 1940s and 1950s the number of new jobs opened in urban areas largely surpassed new offers in rural areas, progressively intensifying the rural exodus. The country entered a transition phase: from an agrarian to an industrial society. Rural-urban migration started to reshape the spatial distribution of the population, peaking in the

1960s, and resulting in accelerated and disorganized urban growth, concentrated in major centers such as Rio de Janeiro (Brazil's capital until 1960) and São Paulo, both located in the Southeast region (Simões 2006). While Brazil was experiencing fast urbanization and industrialization, mortality resulting from nutritional deficiency was still high. This contrast brought the discussion of nutrition programs to the governmental agenda (Vasconcelos 2005).

The lack of policies to address the intense migratory flow, the precarious infrastructure in the cities, the absence of an agrarian reform, and the deterioration of urban salaries became exposed during the early 1960s. At that time, IMR deteriorated in the most developed regions of the country (Southeast and South), exactly those where the urban expansion was mostly significant. An economic recession occurred between 1962 and 1967, followed by a period of intense economic growth (1968-1974). After the political transition to a military government in 1964, important investments in education and habitation started to take place, but tough wage adjustments were also imposed (Demo 1981). During 1965-1970, infant mortality observed the lowest decline in Brazil since the 1930s, 3%. Income inequality became an important topic of discussion in the early 1970s, highlighting the deterioration of health conditions of those excluded from the benefits of intense economic growth. In the mid-1970s, 46% of children younger than 5 years had nutritional deficiencies (Vasconcelos 2005). As a response to this and many other challenges, the government established the Social Development Council in 1974, directly connected to the President's office, which was in charge of supporting social policy making (Pinto 2002). Massive social programs with large national coverage were implemented in Brazil in the 1970s, including, among others, initiatives focused on drug distribution to low income population, special assistance to rural workers, promotion of social development in the Northeast region, improvement of housing financing to population with low income, public health interventions to reduce the burden of preventable diseases in the Northeast and in the

Amazon, improvement of epidemiological surveillance, specific actions on nutrition and maternal and child health, and the implementation of the national health system. An initiative of such magnitude was never seen before in Latin America (Simões 1999; Vasconcelos 2005), and these programs had an overall positive impact in social indicators such as education, nutrition, sanitation, vaccination coverage, and access to primary health care, contributing to declines in infant mortality (Simões 1997).

During the 1980s, Brazil was facing a serious economic recession and fiscal crisis (Silva 1992). Development programs were starting to weaken, and structural adjustment programs imposed restrictions on the availability of resources for social programs (Simões and Ortiz 1988; Tavares 1981). A new political era started in 1985, with the end of the military regime. After several economic plans, stability was achieved in the mid-1990s (Giambiagi et al. 2005; Pereira 1994), and new programs specifically targeted to reduce hunger, unemployment and extreme poverty were launched. In 1995, Brazil implemented a conditional cash transfer (CCT) program (the first in Latin America), targeting poor families and conditioned on school enrollment and attendance of all children in school age (Pero and Szerman 2005). Other programs followed, aimed at providing resources to improve access to basic health services and nutrition (Draibe 2003; Santos and Santos 2007; Vasconcelos 2005). The trend continued in the 2000s, focusing on reduction of inequalities and poverty alleviation, and culminated with the implementation of the "Bolsa Família" conditional cash transfer program in 2003, which unified four pre-existing cash transfer programs, and targeted families below a defined poverty line, conditioned on compliance with requirements to attend health checks and maintain school-age children in school (Marques 2005). Currently, the "Bolsa Família" is the largest conditional cash transfer program in the developing world (Lindert et al. 2007), with more than 11.5 million families covered until June 2009 (approximately 48 million people, or 25% of the current population).

Specifically related to health, the Family Health Program, implemented in 1994, aimed at improving access to primary health care, utilizing a community-based approach for local care provision. Health care services are provided by a team comprised of at least one physician, one nurse, one nurse assistant, and up to six community health workers; some teams may also include a dentist and two assistants. Each team is responsible to provide care for up to 1,000 families (or approximately 4,500 people) in a determined geographical area. (Ministério da Saúde 2009b). Other initiatives included special programs tailored to children with physical and mental disabilities, promotion of breastfeeding, expansion of immunization coverage, and control of vitamin A deficiency. A milestone was the implementation of the HIV/AIDS control program, internationally recognized for it success (Berkman et al. 2005; Nunn et al. 2009).

Also important was the special focus devoted to all 1,133 municipalities (or 20.3% of Brazil's municipalities) that comprise the semi-arid region (Figure 1), which extends throughout the Northeast region and parts of the state of Minas Gerais in the Southeast (Ministério da Integração Nacional 2005), and has a population of approximately 20 million. The region is prone to severe droughts since rainfall is concentrated in a short period of 3 to 4 months. During the drought period women and children are forced to walk long distances in search for water. Special initiatives implemented during 2001 and 2003 allowed the construction of water tanks with capacity for 16 thousand liters of water, which capture and store rain water to be used during the months of drought. These initiatives were scaled-up into a new governmental program ("Cisternas") to support the construction of water tanks in the semi-arid region, targeting families living in rural areas and eligible to the "Bolsa Família" CCT program (Brito, Silva and d'Alva 2007).

Demographically, Brazil experienced high population growth between 1940 and 1960, an average of 2.8% per year. After a similar growth between 1960 and 1970, the growth started to decline in the 1970s (2.5%), reaching an average of 1.6% per year during 1991 and 2000 (Simões 2006). The total fertility rate (TFR) remained at high and relatively constant levels between 1940 and 1960 (Carvalho 1980). A modest and slow decline since the early 1900s and small oscillations in fertility in the 1950s and 1960s have been reported (Frias and Carvalho 1994; Simões 2006). Nevertheless, important demographic transformations started in the mid-1960s. In four decades the TFR experienced a dramatic decline: from 6.3 in 1960 to 2.3 in 2000 (Carvalho 1997; Simões 2006). The National Demographic and Health Survey on Women and Children, conducted in 2006, reported a TFR of 1.8, based on the birth history reported for 36 months prior to the interview (Ministério da Saúde 2008). Although fertility declines occurred in all regions and across different socioeconomic groups, the North and Northeast regions had the highest TFRs in 2000, 3.2 and 2.7, respectively, and their transition process was lagged by approximately 10 years compared with other regions (Simões 2006). Fertility declines had important impacts in infant mortality both through reduction in parity and increase in the interval between births (Rutstein 2000).

DATA

All data gathered for this study are detailed by micro-region, which is an areal aggregation of several municipalities (Lima et al. 2002). Brazil is currently divided into 5,565 municipalities, 557 micro-regions, and 5 regions (Figure 1), as defined by the Brazilian Institute of Geography and Statistics (IBGE). We chose the micro-region as the spatial unit of analysis in order to increase the robustness of the indirect estimations of IMR. Only three changes in the boundaries of micro-regions were observed during the study period, and were resolved by reassigning municipalities according to the current definition.

Information on deaths can be obtained through varied data sources in Brazil, but the occurrence of underreporting, especially among children younger than 1 year in rural areas of the North and Northeast regions, is still an impediment to calculate IMR directly. Therefore, indirect techniques of estimation are needed, which demand the use of data only available in Demographic Census and special surveys. In this study we used the Demographic Census data (1980-2000) for the estimation of IMR by micro-regions. We also utilized the National Sampling Household Survey (PNAD) collected in 2004, 2005 and 2006, combined with Census data (1940-2000), to produce IMR estimates by regions. From each source we extracted information on: (i) number of women aged between 15-49 years by 5-year age groups; (ii) number of children ever born classified by age group of mother; and (iii) number of children surviving classified by age group of mother.

Demographic Censuses were also utilized to construct a time series of urbanization (percentage of the population living in urban areas) by micro-region. Data for intercensal years were estimated utilizing the a_i b_i procedure, a mathematical model that allows the decomposition of estimates for larger areas into smaller areas, assuring that the sum of the smaller areas reproduce the initial estimated total for larger areas (Madeira and Simões 1972). Population estimations (total and 0-1 year) for each micro-region were obtained at the Ministry of Health on-line database (www.datasus.gov.br). The data combine Census information and annual estimates produced by IBGE. Data on municipal gross domestic product (GDP) were available through the Institute of Applied Economic Research (IPEA – www.ipeadata.gov.br) for 1980, 1985, 1996, and 1999-2006. All GDP data were expressed in constant 2000 Reais (the Brazilian currency). We aggregated the municipal data to the micro-region level, and linearly interpolated the data for the years 1990 and 1995 in order to match our time series of estimated IMR.

The availability of data on social programs detailed by micro-region is limited, especially for those implemented by the Brazilian government before the 1990s. We were able to gather information on the Family Health Program from the Ministry of Health on-line database. Data were available since 1998, and included the total number of people and the total number of children younger than 1 year of age registered in the program. From the Ministry of Social Development and Fight against Hunger (MDS) website we acquired all information available for the "Cisternas" and the "Bolsa Familia" CCT programs (Table 1). The total number of water tanks built in each municipality was obtained for 2003-2006, and the total number of families receiving the "Bolsa Familia" in each municipality was obtained for 2004-2006. We utilized the average size of the household by municipality reported in the 2007 Population Count to estimate the total number of people benefited by each program. We aggregated the data to the micro-region level and divided by the total population to obtain measures of program coverage.

METHODS

IMR estimation

Indirect estimations of infant mortality were obtained from information on child survivorship (Brass 1975b; Brass et al. 1968; Feeney 1980; United Nations 1983). The indirect method allows the conversion of proportions dead among children ever born to women in each five-year age group of the reproductive period into estimates of the probability of death, conventionally reported in life tables as ${}_nq_x$, through the application of multipliers that account for non-mortality factors impacting the proportions dead (Brass 1975b). These multipliers were estimated based on the West mortality model (Coale and Demeny 1966) of Trussel's variant of the original model (Trussel 1975).

The estimates for ${}_0q_1$ were allocated in time (Brass 1981), resulting in a time series of estimated IMRs from each data source utilized. That series was subjected to small fluctuations due to problems in reporting the exact number of children ever born and children surviving. We addressed this issue by smoothing the series of estimates using a 3-year or 5-year moving average, depending on the degree of fluctuations. The smoothed series was adjusted by a logistic function to estimate and project IMRs. The estimation exercise for regions utilized both Census and PNAD data. The use of PNAD information for 2004-2006 provided recent mortality estimates that facilitated the adjustment by the logistic (while the Census 2000 allowed us to obtain indirect estimates allocated until 1998, PNAD data generated estimates until 2004). In the case of micro-regions, we used only Census data, since the sample design of PNADs does not allow the disaggregation at the micro-region level (Simões 1999).

We assessed the compatibility between estimates obtained at larger geographical units and those generated for lower geographical units (regions with Brazil, States with regions, and micro-regions with States). The basic procedure consisted of obtaining estimates of births utilizing the P/F ratio method (Brass 1975a; Brass et al. 1968), calculating the number of deaths by relating the estimations of infant mortality and births, aggregating the number of deaths to the larger geographical unit, and comparing that number with the deaths obtained by relating the estimations of infant mortality and births for that larger areal unit. In the rare event of significant disparities between the two numbers, we preserved the estimations for the smaller geographical units, and improved the adjustment of the larger areas by the logistic function accordingly (Simões 1999). In addition, we assessed the sensitivity of the estimations by evaluating the relationship between the infant mortality in each micro-region and the State, which we expect to remain roughly constant in the short run. All calculations were performed in Excel (Microsoft, Seattle, WA, USA), and STATA v.10 (Stata Corp., College Station, TX, USA).

Inequality indicators

Inequality in infant mortality was assessed through the use of two indicators. First, we adapted the concept of inequity ratios proposed by Victora and colleagues (2000) to compute ratios that compare the extremes in infant mortality, providing a measure of the relative gap in the regional distribution of IMRs. In other words, we computed the ratio between the smallest and the largest IMR estimated for each year to evaluate whether or not inequality in infant mortality was decreasing. Second, we calculated the concentration index (Wagstaff 2000; Wagstaff, Paci and van Doorslaer 1991; Wagstaff, van Doorslaer and Paci 1989), considering the micro-region as the unit of analysis, the municipal GDP aggregated to the micro-region as an income-related indicator, and the infant mortality as the health variable. For each decile of the GDP distribution we obtained the total number of children aged 0-1 and the average IMR, from which we estimated the number of deaths. Negative numbers of the index indicate that infant deaths are concentrated among poor micro-regions, or those with the lowest GDP. All calculations were performed in Excel and STATA v.10.

Spatial clustering

The presence of spatial clusters of high and low IMR were assessed through the use of a local indicator of spatial association (LISA), specifically the local Moran's I_i statistic (Anselin 1995; Cliff and Ord 1973). Standard normal variates for the statistic, $Z(I_i)$, were computed and the assessment of significance was based on a normal distribution: significant high values of $Z(I_i)$ indicate positive spatial autocorrelation – cluster of similar values (either high or low), while significant low values of $Z(I_i)$ indicate negative spatial autocorrelation – areas of dissimilarity (Anselin 1995). The weight matrix was defined based on a first-order queen neighborhood definition. All results were corrected for multiple testing utilizing the False Discovery Rate control procedure (Benjamini and Hochberg 1995; Castro and Singer 2006).

We calculated local Moran's I_i for each year of available IMR estimates. In addition, we applied the LISA statistic to the percentage change of IMR observed during each 5-year period from 1980 to 2005, in order to assess if relative reductions in IMR were spatially randomly distributed or concentrated in particular areas. Moran's I_i calculations were performed in GeoDa™, FDR corrections were done in Excel, and results were visualized in ArcMap (ESRI, Redlands, CA, USA).

Change model

We utilized our longitudinal data on estimated infant mortality by micro-regions to assess how the IMR for each area changed over time, and how the IMR change differed across areas. Those questions comprise a multilevel model for change, also called a random coefficients model (Singer and Willett 2002). In the first level of the model we addressed within–micro-region changes in infant mortality, and in the second level we appraised between–micro-region differences in infant mortality change. We collapsed the two levels into one composite model, assuming a linear functional form:

$$IMR_{ij} = [\gamma_{00} + \gamma_{10} TIME_{ij} + \gamma_{s0} W_{ijs} + \gamma_{0k} X_{ik} + \gamma_{1k}(X_{ik} * TIME_{ij})] + [\xi_{0i} + \xi_{1i} TIME_{ij} + \varepsilon_{ij}]$$

In this model, IMR_{ij} represents the infant mortality for micro-region i at occasion (time) j. *TIME* represents years for which we obtained IMR estimates, and is centered on 1980 (the first year of our time series) so that model estimates represent initial status. X_{ik} represents a set of k time invariant predictors, W_{ijs} represents a set of s time varying predictors, and the terms in the second set of brackets represent the composite residual of the model (Singer and Willett 2002).

Also, the parameters in the model have specific interpretations: γ_{00} and γ_{0k} describe inter–micro-region differences in initial states; γ_{10} and γ_{1k} describe inter–micro-region differences in infant mortality change; γ_{00} and γ_{10} represent the average initial status and rate of change, respectively, of the infant mortality (intercepts of the second level); γ_{0k} and γ_{1k} represent the effect of each predictor *k* on the infant mortality change trajectories, and provide a measurement of increments (or decrements) to average initial status and rate of change, respectively (slopes of the second level); γ_{s0} represents the average difference, over time, in infant mortality due to predictor *s*; ε_{ij} represents the residuals of the first level, and indicate the fraction of IMR in micro-region *i* that is unpredicted on occasion *j*; lastly, ξ_{0i} and ξ_{1i} represent residuals of the second level, and indicate the portion of initial IMR status and rate of change, respectively, not explained by the model.

We applied the model described above in two ways. First, we utilized IMRs estimated for 1980, 1985, 1990, 1995, 2000, and 2005 to assess a long-term trajectory of changes in infant mortality. In this model, we included the following predictors: dummy variables representing the regions (South was used as reference); a dummy indicating if the micro-region tested significant for a cluster of high IMR in 1980 (based on the local Moran's I_i); GDP expressed in the natural logarithmic scale in order to address the skewness in the distribution, commonly found in income-related variables; percentage of population living in urban areas, centered around a constant of 40%; and year specific effects as an attempt to control for unobserved temporal characteristics that could potentially impact all micro-regions (e.g. policy changes). Both GDP and urbanization are time-varying predictors. Second, we used a series of estimated IMRs for 1998-2006 to evaluate whether the Health Family Program impacted the trajectory in infant mortality. In addition to the regional dummies, GDP, cluster indicator, and year effects, this model also included the following time-varying predictors: percentage of the population in the micro-region covered by the Health Family Program; percentage of children under the age of one in the micro-region covered by the Health Family Program; and 1-year lagged terms for the previous two variables. Deviance-based tests and the Akaike Information criterion (AIC) were used to assess goodness-of-fit (Singer and Willett 2002). All calculations were performed in STATA v.10.

RESULTS

Indirect estimations of infant mortality: temporal declines and inequalities

We applied the indirect methods of infant mortality estimation to each one of the 557 micro-regions, to the five regions, and to aggregated country data (Simões 1999). Figure 2 shows the steps of the estimation for one specific micro-region, named Maceió, located in the Northeast region. We assembled a time series of IMR estimates for years ending in zero or five for Brazil and regions (1930-2005), and for micro-regions (1980-2005). Utilizing the year 2000, we calculated the ratio between the estimated IMR for the micro-region and the estimated IMR for the corresponding State. We assumed that this relationship would hold roughly constant within a 5-year period, and applied these ratios to the estimated IMR for the State in 2005, generating a new set of estimated IMRs for micro-regions in 2005. The results did not significantly differ from those estimated indirectly. All these estimates of infant mortality are currently in use by the Ministry of Health and by the Pan-American Health Organization (Simões 1999).

The estimated infant mortality for Brazil during 1930-2005, alongside the regions that consistently recorded the lowest and highest IMRs in the country, South and Northeast regions, respectively, are shown in Figure 3. Brazil had an IMR of 162 in 1930, cut in more than half in five decades. Considering a threshold of 30 deaths per 1,000 live births (Bourgeois-Pichat 1952), only two micro-regions were below this mark in 1980, both located in the South region. By the year 2000, all micro-regions in the South and Center-West were below that threshold. The Northeast, however, was the only region with IMRs still above 100 per 1,000 in 1975; at 128 infant deaths per 1,000 live births, the region had mortality levels similar to those recorded for Brazil two decades earlier, despite the significant declines since the 1930s. As a result, only 35% of the micro-regions in the Northeast had IMR below 30 per 1,000 in 2005.

The decline in infant mortality in the regions with the lowest and highest IMRs did not significantly shorten the absolute gap in IMR until 1985, when the two curves started to converge (Figure 3). However, this result per se does not provide an indication that inequalities between the two regions were also being reducing. In fact, the inequity ratio oscillated around an average of 1.7 until 1975, jumping to 2.5 in 1980, and reaching a peak of 2.7 in 1985. Although a steady decline has been observed since 1985, the IMR of the Northeast region in 2005 was still twice as big as the IMR of the South region, a ratio bigger than that recorded back in 1930. Considering micro-regions, the absolute gap between the highest and lowest IMR declined almost 100 points between 1980 and 2005, nonetheless the inequity ratio remained roughly constant at approximately 6.7 (Figure 4).

A question raised by these results relate to changes in the IMR ranking: Are the declines in infant mortality barely changing the ranking of micro-regions regarding IMR? Figure 5 suggests that although fluctuations in the IMR ranking did happen, the top 100 micro-regions (with lowest IMRs) were restricted to the South and Southeast regions both in 1980 and 2005, while those occupying rank 400 and above (highest IMRs) were primarily from the Northeast region (with a few from the North region). Considering changes in ranking observed in every 5-year period during 1980 and 2005, only 55 micro-regions consistently improved their ranking, a third of them located in the Northeast region. Half of these micro-regions in the Northeast were in Ceará, a State that implemented a unique package of public health interventions to improve child health in the late 1980s, recognized in 1993 with UNICEF's Maurice Pate award (Silva et al. 1999; Simões and Ortiz 1988; Victora et al. 2000).

Considering the percentile distribution of the GDP, we found that 65% of the micro-regions within the 10% lowest GDP in 1980 were located in the Northeast region (85% if we considered both the North and Northeast); only 4% were in the Southeast. Among the 10% highest GDP, 46% of the micro-regions were in the Southeast (65% if we combine the South and Southeast). While the distribution among the lowest 10% did not change significantly in 2005, the highest 10% became more concentrated in the Southeast, 53% (or 73% combining the South and Southeast). The health concentration index revealed that poorer micro-regions, as measured by the GDP, were always in disadvantaged position regarding deaths among infants, when compared to richer micro-regions (Figure 6). The situation deteriorated between 1980 and 1995, a period of severe economic instability and fiscal crisis (Silva 1992). After 1995, the index started to improve, although the concentration index in 2005, -0.11, was not statistically different from that observed in 1980. Therefore, the recent improvement could be interpreted as a recovery from 1980s losses.

Spatial clustering of infant mortality

We mapped infant mortality by micro-regions utilizing cutoffs of 30 per 1,000 for low IMR, and above 50 per 1,000 for high IMR (Figure 7). While the vast majority of micro-regions had IMRs above 50 in 1980, progressively declines in infant mortality resulted in a complete change of levels in 2005, when the majority had IMRs below 30. A visual inspection of Figure 7 suggests that declines in IMR were steadily observed in all regions, but the Northeast still concentrated the highest mortality among infants. Indeed, the local Moran's I revealed that significant clusters of low IMRs were consistently observed mainly in the South and Southeast regions of the country, while significant clusters of high IMR were frequently located in the Northeast (Figure 8).

Therefore, despite the decline in infant mortality during 1980 and 2005, the spatial clustering pattern of IMRs remained roughly unchanged. Combined with the deterioration of the concentration index between 1980 and 1995, this finding called for an investigation of the clustering pattern of the relative rate of change in infant mortality for each 5-year period included in the analysis. Figure 9 shows a clear geographical divide: between 1980 and 1990, significant clusters of low decline in IMR were observed in the northern portion of the country, while the southern portion registered the largest gains. This division progressively weakened, and the period 2000/2005 recorded a unique pattern and milestone change: all significant clusters of high infant mortality decline were observed in the Northeast region.

Modeling infant mortality change

We fit 5 different models to assess the long-term trajectory of changes in infant mortality (Table 1). The variance components of Model 1, an unconditional means model, indicated that approximately 35% of the variation in IMR was attributable to differences among micro-regions. Model 2, an unconditional growth model, estimated that 96% of the within–micro-region variation in infant mortality was associated with changes over time. A correlation coefficient based on level 2 variance components indicated a strong and negative correlation between the true IMR rate of change and its level in 1980 (-0.94). In Model 3 we introduced regions as predictors of both initial status and change in infant mortality, and we added year dummies to control for unobserved temporal effects. Taken together, these variables explained 70% of the variation in IMR initial status, and 58% of the variation in IMR rates of change. The estimated IMR initial status for an average micro-region in the South region was 48.2 per 1,000, and 111.3 per 1,000 in the Northeast; the rate of change was 1.3 and 3.2, respectively. Figure 10 shows the estimated trajectories for each region based on this model, as well as the overall average change trajectory based on Model 2. Focusing on the period 2000-2005, the curves suggested that while most regions had an almost flat trajectory, the Northeast region maintained a steep decline in that period, corroborating the pattern shown in Figure 9.

The explanatory power of the model was improved by further adding the 1980 high cluster indicator and the GDP: 79% of the variation in IMR initial status, and 69% of the variation in IMR rate of change were explained by the variables included in Model 4. For each 10% increase in GDP, the model predicted IMR to decline by an average of 0.006, but this effect was barely significant (p=0.011). In the last model we added urbanization as a predictor (Model 5), which was highly significant, indicating that the initial status of infant mortality would be 0.11 points lower for an average micro-region with 40% of the population living in urban areas.

The models presented in Table 2 investigated IMR changes during a shorter and recent time period, 1998-2006, utilizing individual year estimates. Model 1 indicated that 92% of the IMR variation was due to differences among micro-regions. Contrasted with the 35% observed for the long-term trajectory, this finding suggested that, on average, changes in IMR for each individual micro-region were less pronounced during 1998-2006, reinforcing the pattern shown in Figure 10, and corroborated by the much lower average change estimated in Model 2 (0.98 per year, against 2.2 in the long-term change model).

Including regional and year dummies (Model 3) explained 67% of the variation in initial status of infant mortality, and 72% of the variation in rates of change. The initial status of IMR for an average micro-region in the South and Northeast regions was 19.8 per 1,000 and 44.9 per 1,000, respectively, resulting in an equity ratio of 2.3, the same observed in the long-term trajectory (Table 1, Model 3). This finding reinforced the pattern observed in Figure 4: the relative gap between better off and worse off micro-regions did not significantly changed after the declines in infant mortality.

The last two models attempted to provide an initial assessment of the potential association between the Family Health Program and changes in infant mortality. Model 4 suggested that the infant mortality among micro-regions would be reduced as the population covered by the program increased, but higher as the coverage of children under the age of one increased. The distribution of these variables indicated that, in 2006, 62% and 24% of the total and younger than one year population were covered by the program. Regionally, coverage of the total population in the Northeast was 77%. Both the South and Southeast regions had approximately 50% coverage. In the case of children younger than one year, the coverage in the South, Southeast and Northeast regions are the same, about 24%. Therefore, the region with overall highest IMRs did have the highest coverage of the program considering the total population. However, this clear distinction was not true for coverage of children under the age of one. The use of 1-year lag terms (Model 5) did not improve the fit.

DISCUSSION

Our spatio-temporal analysis of infant mortality by micro-regions in Brazil demonstrates that significant reductions have been observed, particularly since the 1970s, although the changes did not alter significantly the clustering pattern of high and low IMRs in the country. Better outcomes remained concentrated in the Southern regions, while higher infant mortality was, for the most part, restricted to the Northeast region. Of special note is the fact that the spatial pattern of rates of change of infant mortality was dramatically transformed during the 2000-2005 period, when significant reductions in IMR were clustered in the Northeast. Equally important is the fact that these declines were not accompanied by significant reductions in inequality of infant mortality. The relative gap between the better off and the worse off micro-regions remained unaltered, and therefore infant deaths remained disproportionally concentrated among the poorest areas. These findings were confirmed by results of the multilevel model for change.

Before we present an in-depth discussion of our findings, a note on data quality is necessary. Despite improvements in coverage of the registration of vital events, and the development of new health systems to report deaths, under-reporting of births and deaths is still a problem, especially in the northern part of Brazil. Therefore, the use of indirect methods of estimation is the only option to produce reliable indicators of infant mortality, allowing an assessment of regional disparities, and facilitating the implementation of special programs to target those most in need. Indeed, IMR estimates produced at different geographical units, regularly provided to the Ministry of Health (Simões 1999), were the basic information for defining a recently launched program to reduce infant mortality, which targets 250 municipalities – 154 in the Northeast region and 96 in the North region (Ministério da Saúde 2009a). In addition, the government has intensified actions to improve the vital registration system in the northern portion of the country, utilizing local estimates of the under-reporting of events provided by these indirect methods.

Our results cannot be used as direct evidence of the inverse equity hypothesis, since a multitude of social, economic, and public health changes and interventions were occurring concurrently during the study period (Victora et al. 2000). Nonetheless, considering that the IMR in the most privileged regions of the country was still above 80 per 1,000 in 1970, there was much room for the richer to take advantage of the services provided through those various interventions, making it more difficult to reduce the gap between the poor and the rich. That was specially the case for interventions with national coverage and, therefore, available to any segment of the population. Although a few targeted programs were also implemented over the years, a major shift in the social policy agenda took place in mid 1990s, with the introduction of conditional cash transfer programs, considered to be an effective tool toward poverty reduction (Barrientos and DeJong 2004, 2006). Although the recent decline in the regional equity ratio presented in Figure 3 may suggest the success of those programs to effectively reach those most in need, the roughly flat ratio for micro-regions (Figure 4) indicated that local variabilities at smaller scales still persisted.

Regarding conditional cash transfer programs, "Bolsa Família" allows poor families to have access to varied goods (e.g., food) through the transfer of monthly payments, potentially contributing to reduction in inequalities; indeed, 21% of the decline in the Gini index in Brazil between 1995 and 2004 was attributed to the "Bolsa Família" program (Soares et al. 2006). In addition, its conditionalities (e.g., immunization of children, attendance to school, regular health checks) aim to facilitate the improvement of social and health indicators. While "Progresa", the conditional cash transfer program in Mexico, was associated with a 11% decline in infant mortality among those covered in rural areas (Barham 2006), no formal evaluation of the impact of "Bolsa Família" on infant mortality in Brazil has been undertaken. Data are available only for 2004-2006. Moreover, since the program unified four pre-existing programs, attempts to utilize a longitudinal model of change (as we applied in this paper) without information prior to 2004 could result in overestimation of the real impacts of the program. The same applies to the "Cisternas" program, whose impact on infant mortality in Brazil has not been evaluated either. Until 2008, of the estimated demand of 1,186,601 water tanks – benefiting 4,978,876 people (d'Alva and Farias 2008), 17% have been constructed. Longitudinal individual-level data, contrasting recipients and non recipients of the cash transfers and of the water tanks, would be a more appropriate dataset; to this date, we do not possess such data for infant mortality analysis. Nonetheless, both the large coverage of the "Bolsa Família" and the scale-up of the "Cisternas" program are likely to have played important roles on the significant change in the pattern of IMR decline during 2000-2005, as shown in Figure 9.

Previous studies have shown that, considering the 1993 IMR in Brazil, the impact of the Family Health Program on infant mortality has been associated with a decline of 5.6% for municipalities that have been in the program for three years, and 20% for those eight years into the program (Rocha and Soares 2009). At the State level, increases in the coverage of the Family Health Program by 10% were associated with an average of 4.6% decline in IMR (Macinko, Guanais and Souza 2006). Our findings follow the same direction of these previous analyses, and suggest that data on total population covered by the program may be the most appropriate indicators for assessment of program relationships with infant mortality.

Several factors commonly associated with declines in infant mortality (Rutstein 2000) did show improvements recently. The percentage of women that had seven or more prenatal care consults in the country increased from 22% in 1995 to 56% in 2007. The regional distribution, however, is very unequal: approximately a third of women in the northern regions, and about 70% in the South and Southeast. Immunization coverage improved from 46% in 1995 to 82% in

2007, but achieved a much more equal distribution, with both the North and Northeast regions registering coverage above 80% in 2007. Equally important were the gains in education: 43% of women in the reproductive period had only 3 years of schooling in 1980; in 2005 this number was reduced to 12%. The North and Northeast regions had the highest percentages in 2005, 16% and 20%, respectively. Nonetheless, the remarkable 70% decline from 1980 levels observed in these regions was almost certainly a crucial contributing factor for the decline in infant mortality, considering the largely documented impact of women's education on IMR (Caldwell 1979). Another major achievement was the decline in child undernutrition in Brazil since the mid-1970s, intensified since the mid-1990s: while the prevalence of stunting declined between 1975 and 1989 at a rate of 5% per year, it was reduced by 6.3% per year between 1996 and 2007 (Monteiro et al. 2009). Although the factors that mostly determined these declines varied over the years, the most recent decline (from 1996 to 2007) was unique since it was a consequence of both increases in maternal education and income, and, to a lesser extent, of better access to health care (Monteiro et al. 2009).

This study has several limitations. First, by using the micro-region as the unit of analysis, we did not address inequality issues within each micro-region: even the micro-region with highest IMR and lowest GDP is likely to have spatial variability regarding infant deaths, and differences in income distribution of the population. Second, we did not include variables on housing infrastructure (e.g., sanitation, water, and electricity), education, and provision of services (e.g., number of doctors per 1,000 people); although often important predictors of infant mortality, due to limitations of data availability by micro-region. Third, the multilevel models for change that addressed the impact of the Health Family Program are likely to be subjected to endogeneity problems. Poor areas often have higher infant mortality and also will draw a large fraction of candidates to enroll in the program. Therefore, a larger coverage of the Family Health Program may result in infant mortality declines due to better access to health care, but high infant mortality levels may also result in program coverage increase aiming at improving access to care and reduce the burden of infant deaths. Which one prevails is yet to be answered. Fourth, since we did not have individual-level data, we could not assess if reductions in infant mortality were observed by the poor, who had access to varied programs (e.g., Family Health, "Bolsa Família", etc.). Lastly, as it is the case with any ecological analysis, the probability of confounding is non negligible; we minimized this problem by including year specific variables.

In summary, the decline in infant mortality and the apparent positive signs of reduced inequalities do send a positive message for the future. The continuation and expansion of current social programs in the coming years are likely to contribute to the maintenance of trends demonstrated in our analysis, although two issues need to be addressed. First, it is important to assess the true causal effects of infant mortality decline, so that current policies may be adapted and/or improved as needed, and new ones devised. Second, it is crucial to improve understanding of the determinants of infant mortality (Black, Morris and Bryce 2003; Hill and Pebley 1989; Mosley and Chen 1984) in the current scenario of lower rates. The year 2010 will be crucial for both issues, since the country will have presidential elections and a new Demographic Census will be undertaken. The outcome of the elections will determine how smooth the transition between the old and the new government will be and, therefore, whether current policies will be continued or not. The Census will allow revision of the IMR estimates here presented, and provide much needed individual-level data to comprehensively appraise the determinants of infant mortality and the causes of the decline here described.

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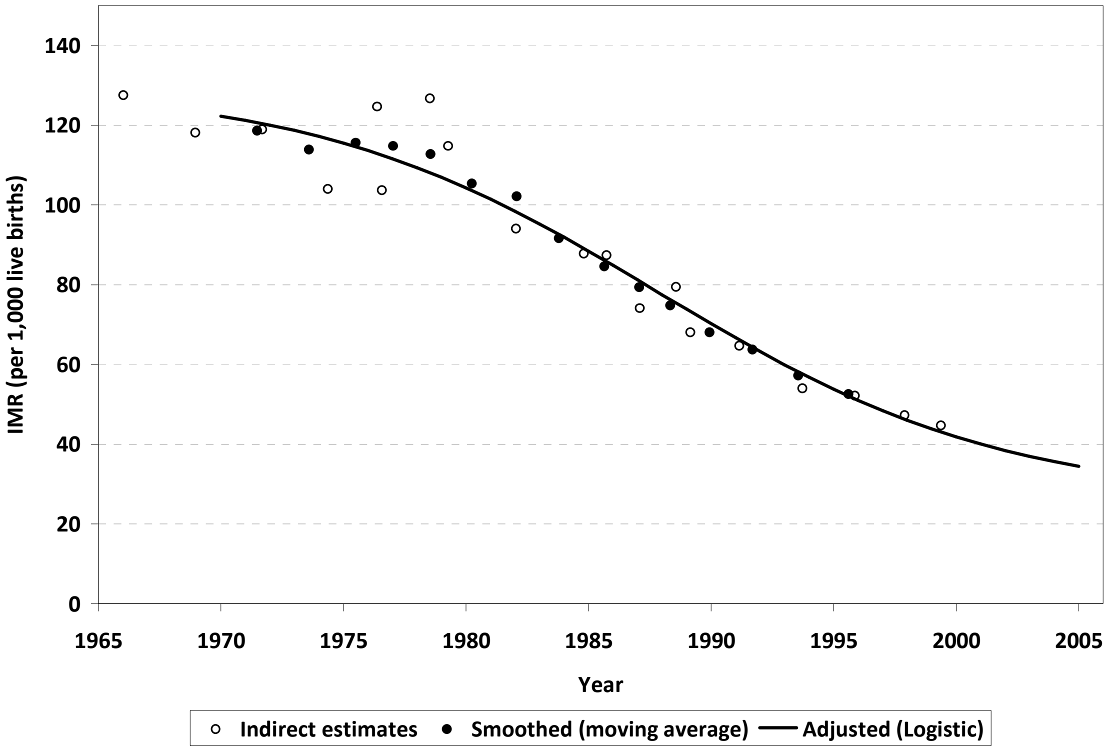
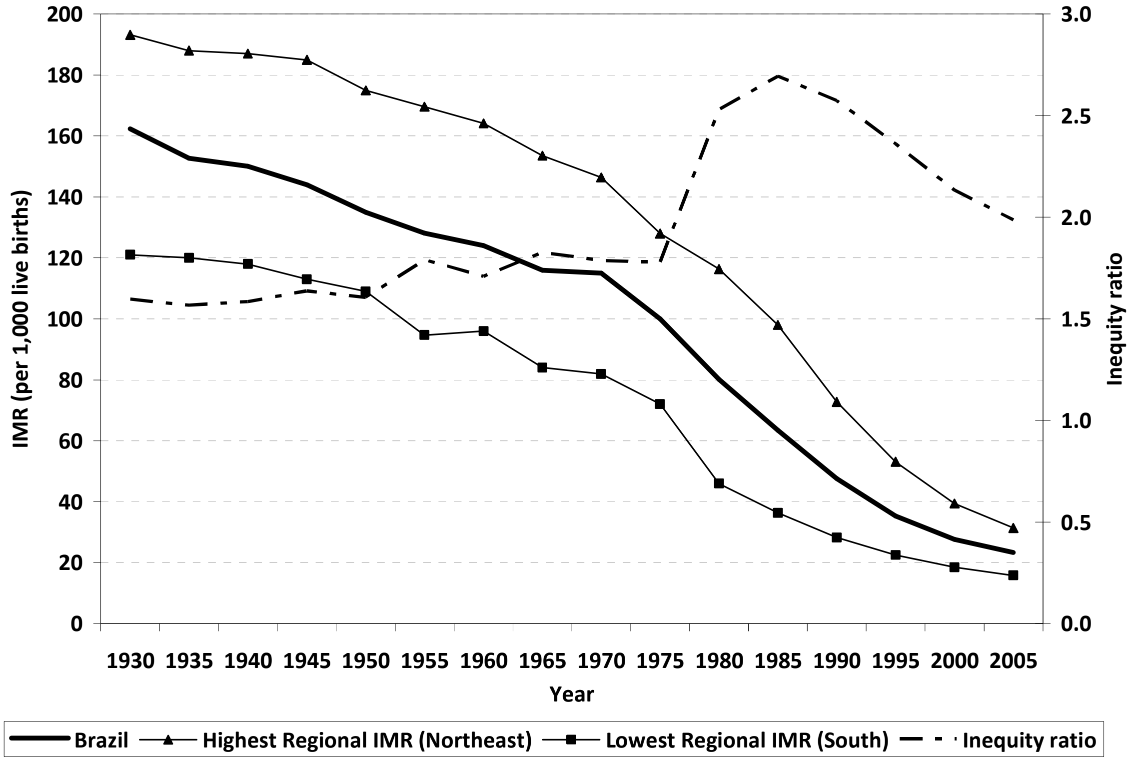
Figure 1 – Delineation of the semi-arid region in Brazil and selected administrative divisions (regions, micro-regions and municipalities)

Figure 2 – Estimated infant mortality for Maceió micro-region – 1970-2005



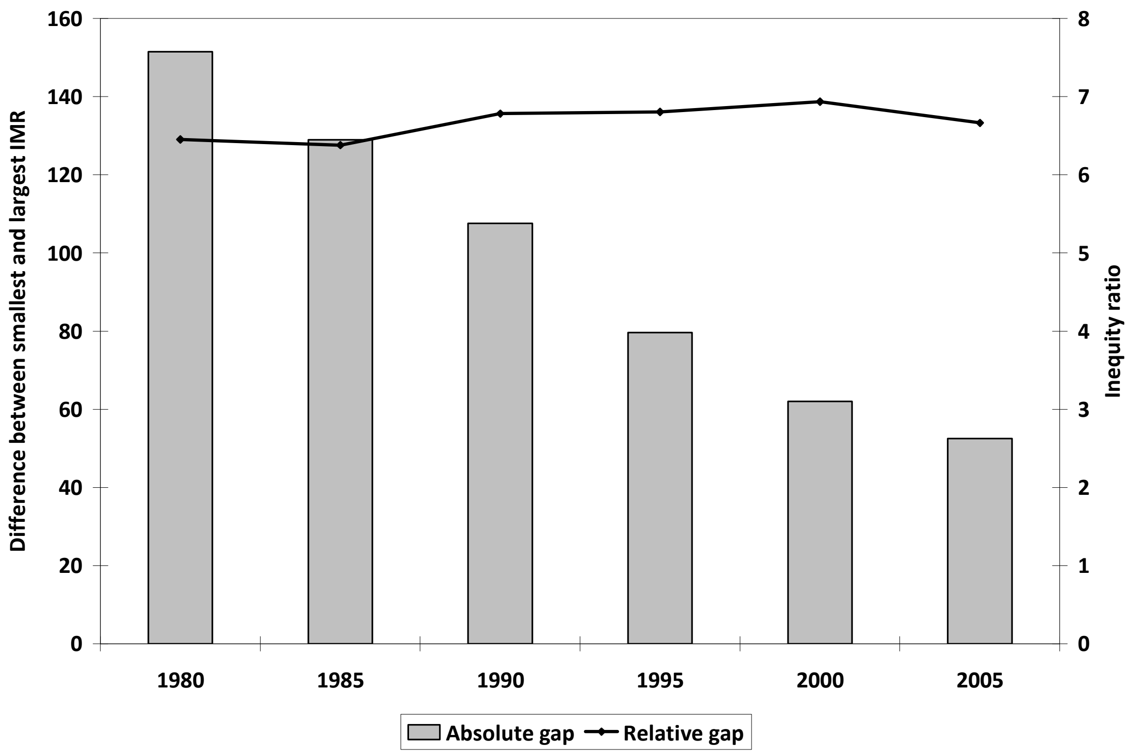
Source: Indirect estimations produced by the authors (details provided in Methods section).

Figure 3 – Infant mortality rates, Brazil and regions with consistently lower and higher rates in the country – 1930-2005



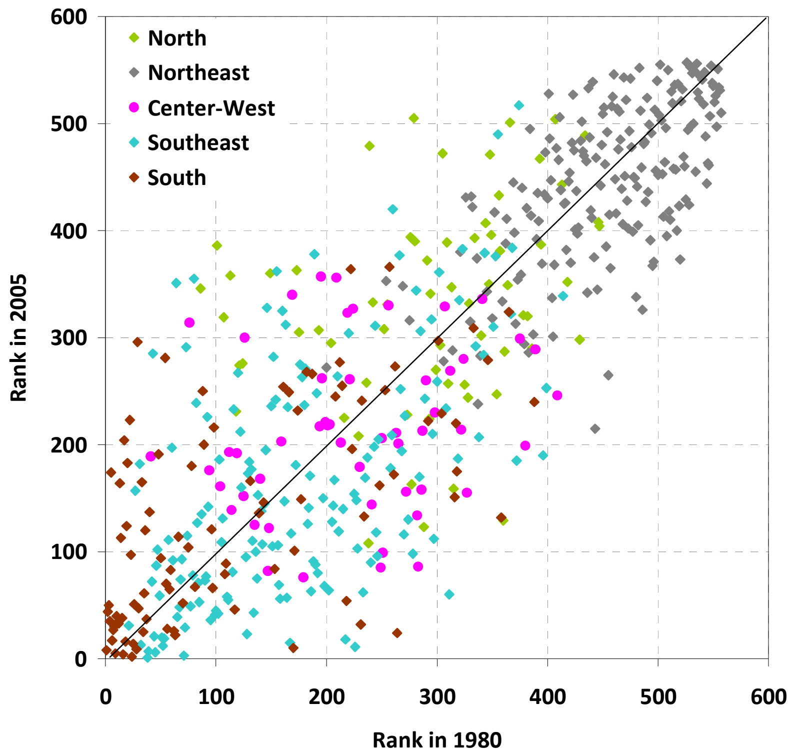
Source: Indirect estimations produced by the authors (details provided in Methods section).

Figure 4 – Equity ratios and absolute difference between the smallest and largest IMR estimated for micro-regions – 1980-2005



Source: Indirect estimations produced by the authors (details provided in Methods section).

Figure 5 – Changes in the ranking of micro-regions according to estimated infant mortality (rank 1 = lowest IMR) – 1980 and 2005



Source: Indirect estimations produced by the authors (details provided in Methods section).

Figure 6 – Concentration Index of infant deaths by micro-region GDP – 1980-2005

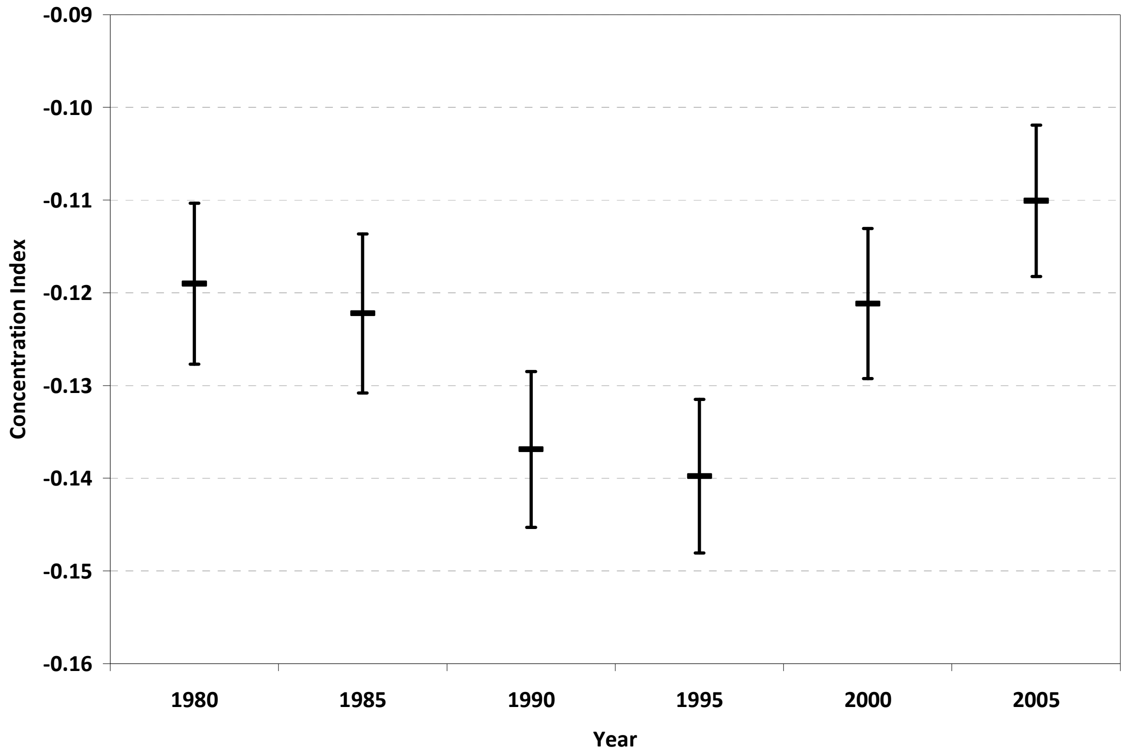
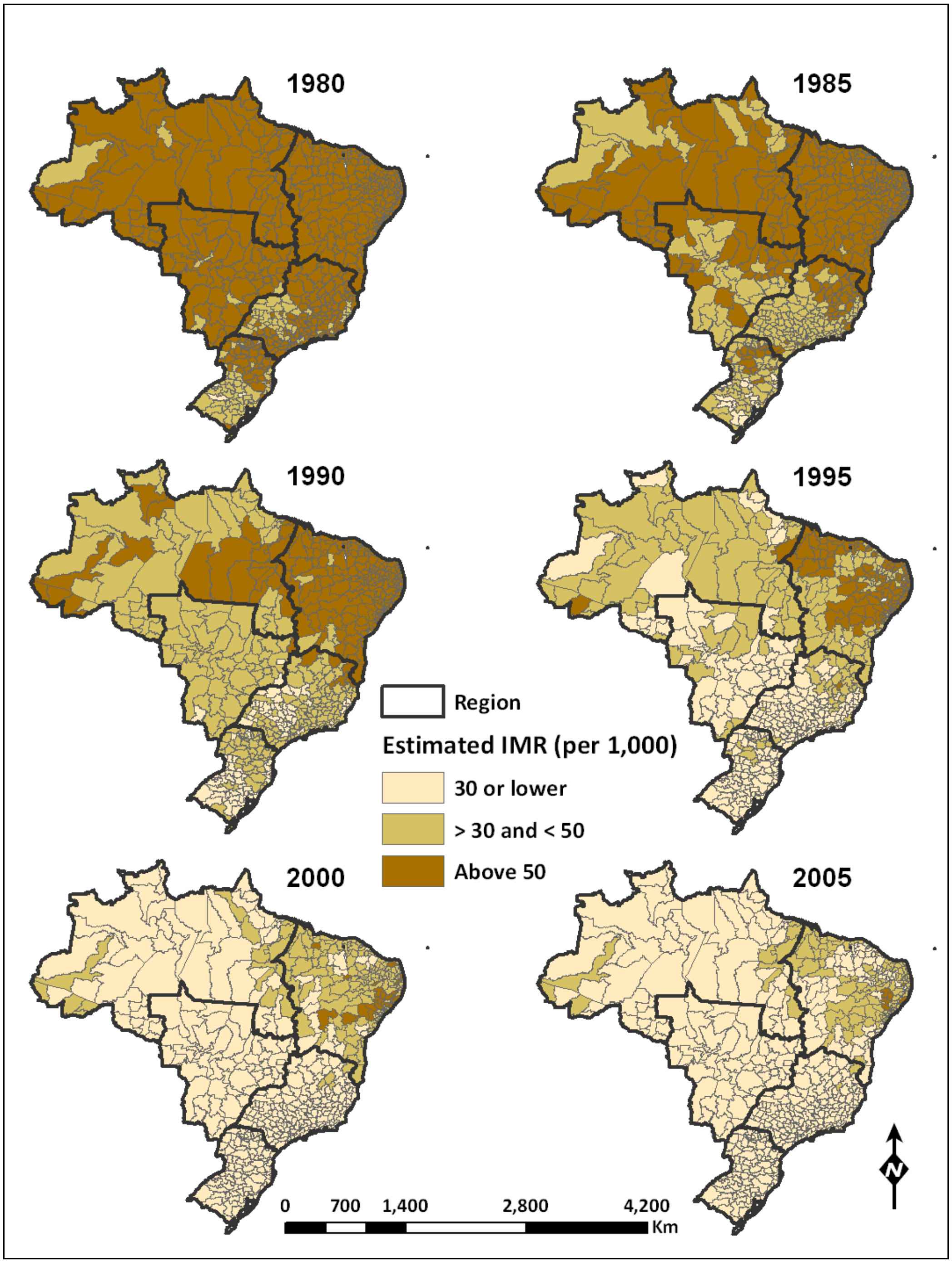


Figure 7 – Infant mortality per 1,000 live births by micro-region – 1980-2005



Source: Indirect estimations produced by the authors (details provided in Methods section).

Figure 8 – Summary of clustering pattern of infant mortality by micro-region and based on estimated IMR for 1980, 1985, 1990, 1995, 2000 and 2005

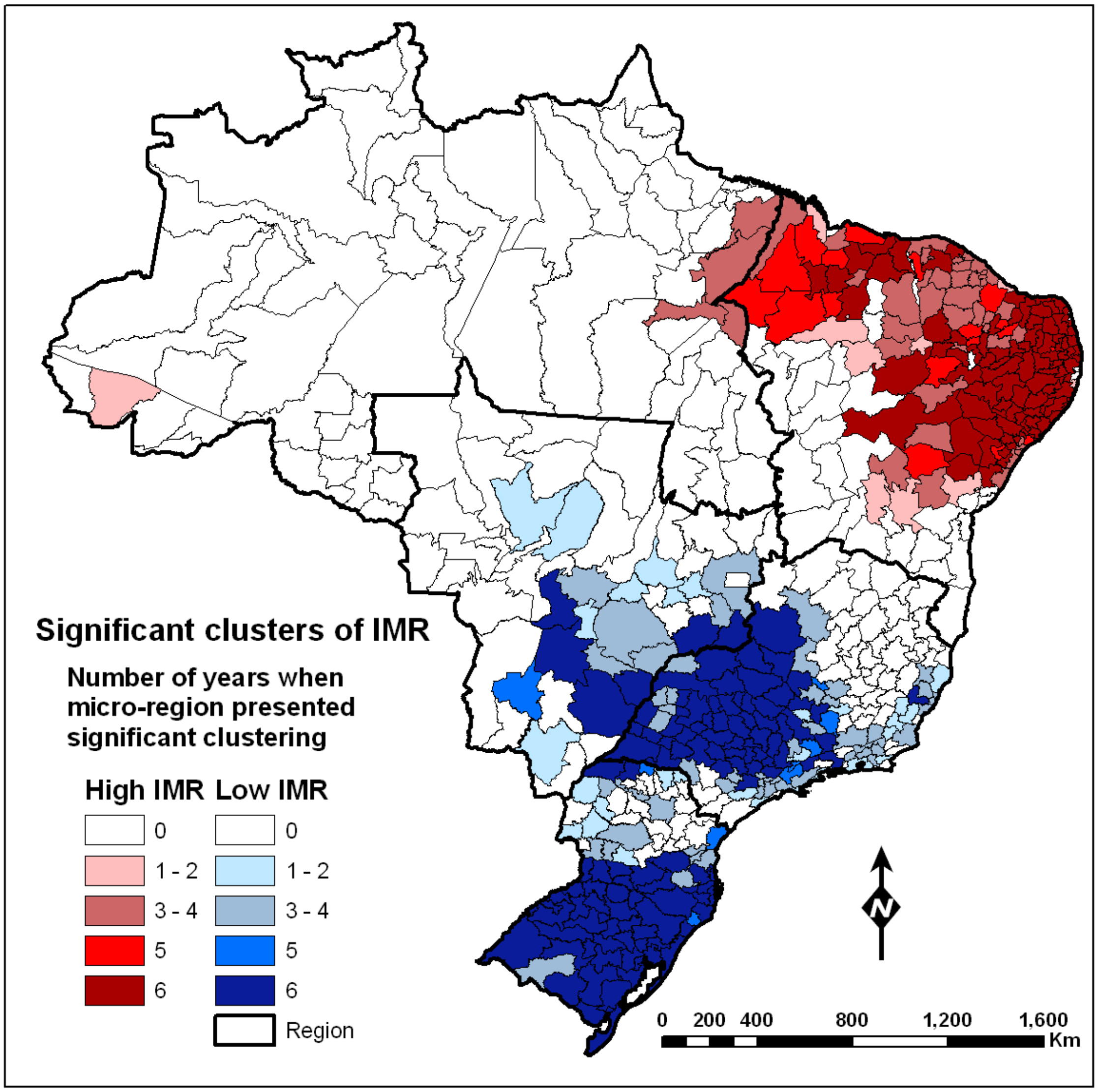


Figure 9 – Clustering pattern of percentage changes in infant mortality by micro-region for each 5-year period between 1980 and 2005

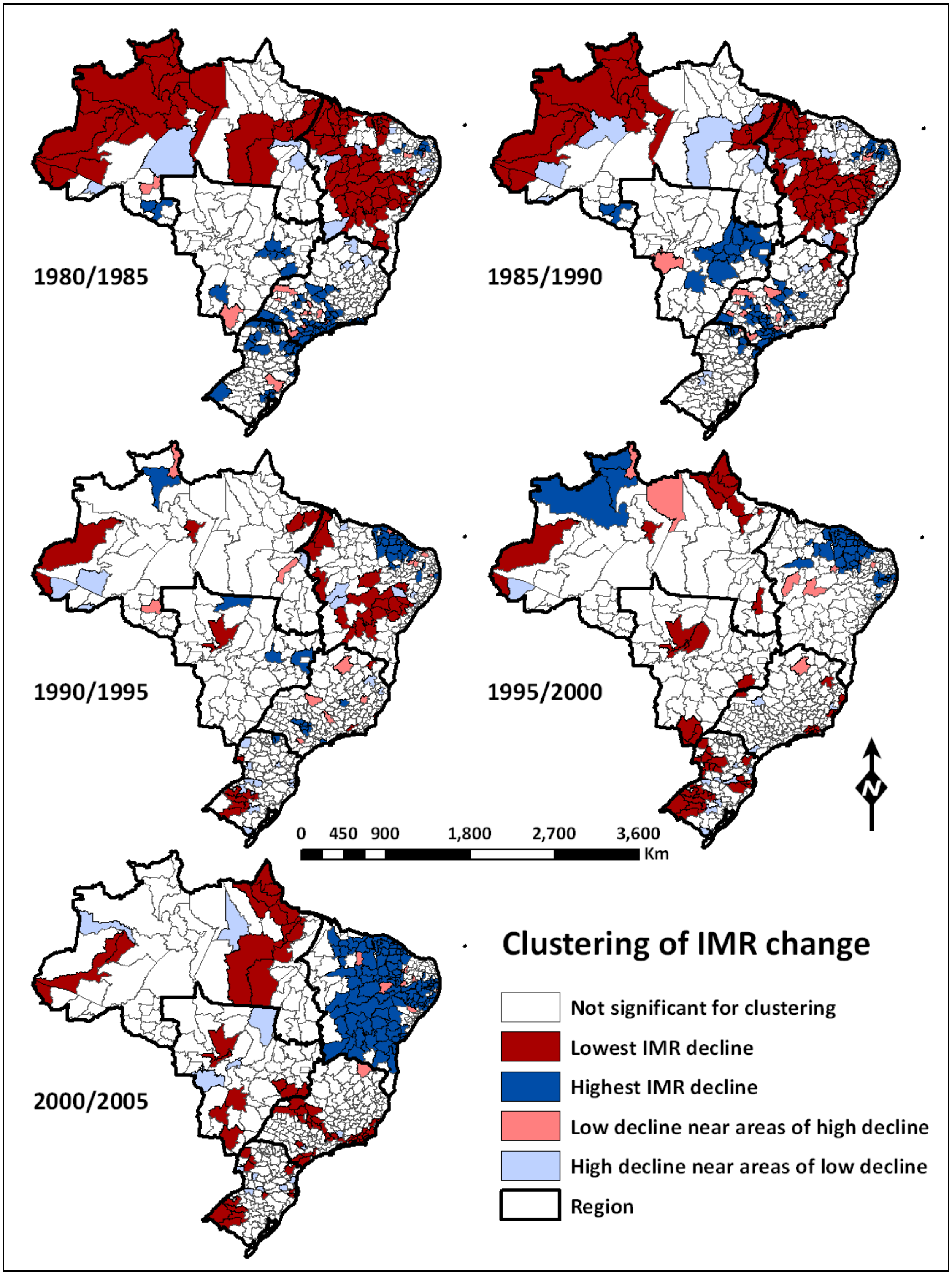


Figure 10 – Trajectories of change in infant mortality by region based on a multilevel model that control a year specific effect (Model 3). The average trajectory is based on the unconditional growth model (Model 2).

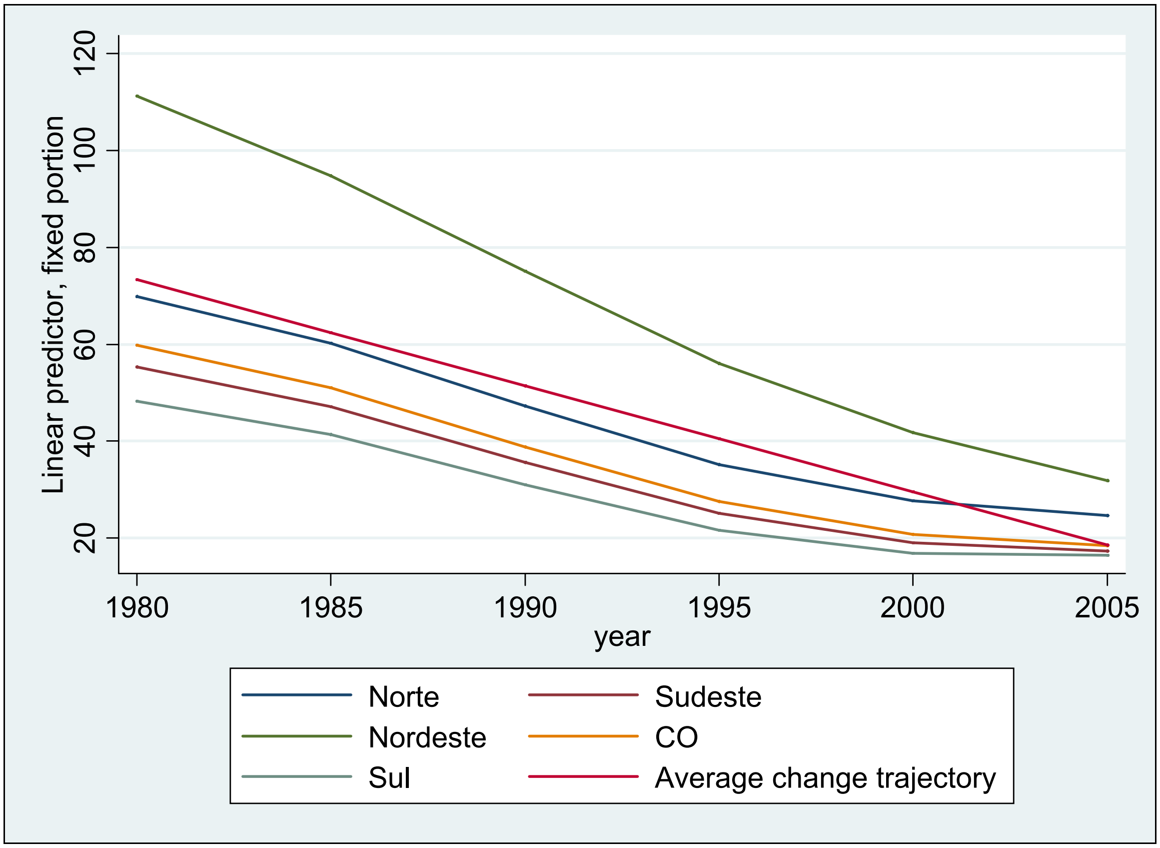


Table 1 – Models of initial status and change in infant mortality rates by micro-regions – 1980, 1985, 1990, 1995, 2000 and 2005

			Mod. 1	Mod. 2	Mod. 3	Mod. 4	Mod. 5
Fixed effects	Intercept	γ_{00}	45.931	73.314	48.214	58.259	48.143
	1985	γ_{01}			-0.551	-0.511	-0.556
	1990	γ_{02}			-4.482	-4.472	-4.483
	1995	γ_{03}			-7.513	-7.656	-7.496
	2000	γ_{04}			-5.941	-5.962	-5.938
	North	γ_{05}			21.641	20.934	20.307
	Northeast	γ_{06}			63.083	39.689	39.095
	Southeast	γ_{07}			7.086	7.085	8.584
	Center-West	γ_{08}			11.585	11.069	12.003
	Cluster high IMR, 1980	γ_{09}				33.645	33.782
	ln(GDP)	γ_{20}				-0.492^{ns}	0.061^{ns}
	Urbanization	γ_{30}					-0.107
Rate of change	Intercept	γ_{10}		-2.191	-1.272	-1.262	-1.171
	North	γ_{15}			-0.538	-0.530	-0.531
	Northeast	γ_{16}			-1.906	-1.064	-1.069
	Southeast	γ_{17}			-0.247	-0.244	-0.273
	Center-West	γ_{18}			-0.382	-0.370	-0.371
	Cluster high IMR, 1980	γ_{19}				-1.243	-1.252
Variance components:							
Level 1	within	σ^2_ε	532.384	22.022	9.546	9.564	9.545
Level 2	rate of change	σ^2_1		1.034	0.431	0.317	0.318
	initial status	σ^2_0	291.133	996.578	302.776	215.598	214.484
	covariance	σ_{01}		-31.277	-10.633	-7.494	-7.516
Goodness-of-fit:							
	Deviance		31217.0	23121.3	20537.1	20347.9	20322.9
	AIC		31223.0	23133.3	20573.1	20389.9	20366.9

Note: ^{ns} = not significant. The year 2005 was removed due to collinearity.

Table 2 – Models of initial status and change in infant mortality rates by micro-regions – 1998-2006

			Mod. 1	Mod. 2	Mod. 3	Mod. 4	Mod. 5
Fixed effects	Intercept	γ_{00}	25.748	29.665	19.848	20.679	20.658
	1999	γ_{01}			-0.571	-0.585	-0.599
	2000	γ_{02}			-0.942	-0.933	-0.979
	2001	γ_{03}			-1.125	-1.080	-1.136
	2002	γ_{04}			-1.154	-1.099	-1.130
	2003	γ_{05}			-1.038	-1.006	-1.004
	2004	γ_{06}			-0.797	-0.769	-0.781
	2005	γ_{07}			-0.446	-0.437	-0.434
	North	γ_{08}			10.449	10.059	10.073
	Northeast	γ_{09}			25.088	18.813	18.813
	Southeast	γ_{010}			1.955	2.295^{ns}	2.286^{ns}
	Center-West	γ_{011}			3.698	3.874	3.854
	Cluster high IMR, 1980	γ_{012}				8.721	8.691
	Urbanization	γ_{20}				-0.033	-0.032
	% coverage HF-T	γ_{40}				-0.008	
	% coverage HF-C	γ_{60}				0.007	
	lag % coverage HF-T	γ_{80}					-0.006
	lag % coverage HF-C	γ_{100}					0.003
Rate of change	Intercept	γ_{10}		-0.979	-0.555	-0.492	-0.495
	North	γ_{18}			-0.312	-0.311	-0.315
	Northeast	γ_{19}			-1.097	-0.823	-0.828
	Southeast	γ_{110}			-0.079	-0.091^{ns}	-0.089^{ns}
	Center-West	γ_{111}			-0.100	-0.080^{ns}	-0.079^{ns}
	Cluster high IMR, 1980	γ_{112}				-0.379	-0.374
Variance components:							
Level 1	within	σ^2_ε	9.865	0.334	0.103	0.099	0.100
Level 2	rate of change	σ^2_1		0.312	0.088	0.076	0.076
	initial status	σ^2_0	120.641	171.938	56.557	49.306	49.371
	covariance	σ_{01}		-6.903	-1.815	-1.510	-1.518
Goodness-of-fit:							
	Deviance		28273.5	14474.7	9153.1	8932.0	8972.0
	AIC		28279.5	14486.7	9191.1	8980.0	9020.0

Note: ^{ns} = not significant. The year 2006 was removed due to collinearity.