Spatial dependence and heterogeneity in ten years of fertility decline in Brazil: where, why and how fast

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Abstract:
Knowledge, innovations and behaviors that influence fertility decisions spread over space through teaching/learning processes and often occur through imitation between areas that are closer to each other. In this study, I adopt a spatially referenced approach to take into account this proximity and to analyze why, where and how fast fertility has declined in Brazil. Using data based on the Brazilian Census I investigate the spatial and temporal patterns of fertility in Brazilian municipalities between 1991 and 2000, identify the "hot and cold spots" in which fertility is clustered, and evaluate the importance of relevant socio-demographic factors accounting for these patterns. I do this by estimating and comparing the efficiency of two favorite models: ordinary least squares with spatially correlated errors and geographically weighted regressions (GWR). The results indicate that the last provides the best estimates and demonstrates that the importance of each variable is dependent on its spatial distribution. In particular, the relevance of the fertility in neighboring areas as a predictor for local total fertility rates (TFR) provides initial evidence that fertility may, indeed, follow diffusion mechanisms. The analysis also shows that the endogenous level of fertility prevailing in 1991 is extremely significant to determine how fast fertility declined in ten years. Intriguingly, once this variable is considered in the model, improvements in education do not necessarily have a negative impact on fertility.

Keywords: Brazil, fertility decline, geographically weighted regression, neighborhood effects, diffusion, spatial correlation

Ten years of fertility decline in Brazil: Where, Why and How Fast

Jeronimo O. Muniz

The decline of world's average fertility is notoriously evident and has been broadly documented in the literature (McDonald, 2002; Wilson, 2004; Kohler, Billari and Ortega, 2002, 2005). In Europe, total fertility rates (TFRs) have fallen to surprisingly low levels, while China (Zhao, 2001; Baochang and Feng, 2006) and Thailand are often cited as representatives of below replacement fertility in developing countries (PRB, 2005). Less is know, however, about the importance of socio-economic, ideational and cultural factors on the pace of the decline. In less developed countries, it has been suggested that the fertility transition will take place at a faster pace than that followed in the US and in other European countries. This idea holds if we look at the experience of Kenya (, El Salvador, and Iran, which are the typical examples where fertility declined much faster than anticipated. In Tunisia, women have gone from bearing an average of over seven children in the early 1960s to only 2.3 in the late 1990s. In Brazil, the rate has slumped from 6.3 to 2.4 between 1960 and 2000. For most countries, the decline in fertility rates has been accelerating over the past 25 years, and population experts now think that they will approach the equilibrium rate much sooner than expected (Bongarts, 2005).

On the one hand, it has been argued that the fast decline of fertility is a consequence of individualization, post-materialist values and ideational changes (Notestein, 1952; Van de Kaa, 1994). According to this view, urbanisation, better education and higher social status for women may not represent preconditions for declining fertility[1]. In Ghana, for instance, fertility rate has declined from 7 in the 1970s to 4.2 today, in spite of limited progress on other fronts (PRB, 2005:1; The Economist, 2002). Uneducated women in rural areas, provided they have access to family planning, increasingly choose to have fewer children. As a corollary, one of the reasons why fertility has not declined further in some places is because women have not met their needs for contraception. According to Bongaarts (1994), if these "unmet needs for contraception" were satisfied, about 1.1 billion births would be prevented until 2050.

Of particular interest are the supracited findings of the European Fertility Project, which shows that cultural factors characterized by language, traditions, ethnicity and religion are more important than socio-economic factors to determine the decline of fertility and specially its timing (Van de Walle and Knodel, 1980; Coale and Watkins, 1986). The argument was that fertility trends were much more similar among regions sharing common language, religion, norms and traditions, than among regions with similar socioeconomic characteristics, what corroborates the fact that cultural and

[1] McDonald (2002:427-28), in particular, suggests that the post-materialist theory is an ecological fallacy. Just because women who are more educated, more urban, and more liberal in their attitudes have lower fertility than those who are less educated, more religious, more rural and conservative, it does not mean that there is a causal relationship between their characteristics and fertility. According to McDonald, low fertility is a societal phenomenon related to the structure of social institutions, and in particular to gender equality.

ideational factors may play the most important role in the determination of fertility decline (Cleland and Wilson, 1987). In the words of Cleland (1985): "[T]he culture of a population, loosely defined by religion, language or region, appears to exert a major influence on the timing of reproductive change, independently of levels of development, education, or provision of family planning services." With this evidence in mind, these authors have argued that fertility decline could have preceded economic development (as was the case of France), and that modernization should have been seen as a sufficient but not necessary condition for marital fertility decline. The appearance of new technologies to birth control may have helped to trigger the fertility decline, but more important than that was the change in women's mentality. The idea of manipulating reproduction, the acceptance of new methods and the social propagation of new contraceptive techniques were decisive to engender ideational changes and the fertility decline in Europe.

On the other hand, despite the findings of the European Fertility Project, a few years later Bongaarts (1994) and Bongaarts and Watkins (1996) argued that socioeconomic development were important to predict the onset and the pace of fertility decline in Europe. If socioeconomic developments in Europe had not occurred, the perceptions about costs and benefits of children would not have changed, and more advanced nations would not have experienced an earlier onset of decline. To reduce fertility, Bongaarts (1994) recognizes that it is crucial to invest in human development giving to women the means to make choices, the means to recognize the value of smaller families, while simultaneously increasing the investment in children. Therefore, to change families' perceptions of the costs and benefits of rearing children, what governments can do is to affect (a) education levels, (b) the status of women and (c) child mortality. In addition, the exposure to western norms and traditions brought mainly by television and the mass media can also contribute to decrease fertility via changes in aspirations and tastes – as is the case of Thailand, which reduced fertility rates in more than 40 percent in less than ten years (Knodel et al. 1987; Prachuabmoh and Mithranon, 2003). In Brazil, television has also had substantial unintended and synergistic consequences for reproductive behavior as a source of new ideas and values (Faria, 1989; Faria and Potter, 1999; Rios-Neto, 1987, 2001).

Whether individualization, secularization, socialization, diffusion, adaptation or rational calculus is the cause of fertility trends is an issue in which consensus can be hardly achieved given that all these factors contribute to fertility decisions and influence the number of children wanted by women. Economic and ideational theories are complementary rather than exclusory. Their synergic and simultaneous influences can hardly be disentangled (Lesthaeghe, 1997; Axin and Yabiku, 2001)[2]. Alone, economic and ideational theories are incapable of fully explaining the fertility transition because they assume that the decline has the same cause when, in fact, it is more likely that it has different and multiple causes in different contexts. Fertility transition is best understood

[2] Particularly important to this study is the discussion presented by Potter et al. (2002:740) about the fertility transition in Brazil. They found "strong and consistent relationships between the decline in fertility and measurable changes in social and economic circumstances" in Brazil. Their findings "undermine some of the arguments for ideational change, diffusion, or social interactions", but they do not exclude the possibility of having simultaneous and complimentary effects between material and ideational changes.

by a combination of structural, diffusion and local context in which reproductive decisions are made (Entwisle, 1997). As a result, each decline in each region should be considered separately (Mason, 1997).

One way to address the specificities of each region is to look at smaller units of analysis and to consider that fertility changes in different places may have different responses to changes in cultural and socio-economic variables. From a political point of view, the use of smaller units facilitates the planning and evaluation of public policies and the elaboration of local diagnostics. From an analytical point of view, the use of local units of analysis allows one to consider the specificities and heterogeneities of each region over space. More specifically, the availability of geographically referenced data and the availability of GIS technology have allowed the integration of fertility, socioeconomic variables and space, what has enriched the analysis of reproductive behavior.

The geographically weighted regression (GWR) technique offers a solution to look at the spatial variability of demographic phenomena mediated by spatial processes taking into account spatial heterogeneity and non-stationary coefficients. In particular, for these same reasons GWR models are usually more appropriate than classical ordinary least squares (OLS), OLS with spatial lag, and OLS with spatial errors. They also provide normally distributed, non-auto correlated and low residuals in space according to the Akaike information criterion, what make them more efficient and non-biased than other traditional models (Fotheringham and Brunsdon, 1999; Fotheringham et al. 2002). The use of GWR is particularly relevant to study the influence of socio-economic characteristics on fertility because, besides taking care of spatial heterogeneities, it allows one to incorporate the fertility levels of the surrounding areas, which can be understood as a type of "neighborhood effect" (Tolnay, 1995; Weeks, 2003).

Estimating GWR models for Brazil I shed light on the local importance of economic characteristics, once the influence of fertility in surrounding areas is taken into account. The significance of the spatial variable measuring the presence of neighborhood effects provides evidence to suggest that diffusion[3] and cultural similarity may indeed play a role, such as suggested by the European Fertility Project. Therefore, previous findings emphasizing socio-economic factors (Potter et al. 2002), but neglecting spatial influences and heterogeneities, should be taken with caution.

The analysis that follows is guided by the following questions: **1)** what is the spatial (variability) and temporal (change) pattern of fertility in Brazil? **2)** Where are the

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[3] Diffusion has been suggested as an important factor to explain fertility decline (Cleland, 2001; Lesthaegue and Surkyn, 1988). The idea behind this concept is that knowledge, innovations and behaviors that influence fertility decisions spread over space through teaching/learning processes, which often occur through imitation. If we accept this concept of diffusion, then it is reasonable to say that learning/imitative processes take place in areas that are closer to each other, independently of their socio-demographic characteristics. This type of effect has also been called "neighborhood or environmental context effect on demographic behavior" (Weeks, 2003).

"hot" and "cold" spots in which levels of fertility are clustered? **3)** What are the factors accounting for these patterns and how are they related to fertility changes?

The first question is answered mapping total fertility rates (TFRs) in all municipalities in Brazil in 1991, 2000 and for the change between these two periods. Mapping TFRs show how fertility has changed over the decade and where these changes were more accentuated.

The second question is addressed conducting spatial cluster analysis using the $G_i(d)$ statistics (Getis, 1995), which identifies those areas where high and low fertility is clustered according to specific critical distances (i.e. distances within which fertility is strongly correlated with the surrounding areas) (Weeks et al. 2000).

Finally, to examine the association between theoretically relevant socio-demographic variables and fertility patterns, three Geographic Weighted Regression (GWR) models are estimated – one in 1991, one in 2000 and another one for the change in municipal TFRs between these two periods. In particular, this analysis goes beyond correlations between particular socioeconomic variables and fertility in two points in time by modeling the change in TFRs over the decade. This approach will help to explain how concomitant changes in fertility and socioeconomic variables relate to broader historical trends. Variables in the models include child mortality, sex ratio of people older than age 15, urbanization rate, index of education, female labor force participation (in 2000), percentage of whites, and the fertility of surrounding areas, which will be responsible for indicating the presence of neighborhood effects[4].

Fertility Trends in Brazil

Fertility decline in Brazil has been recognized as remarkably fast. Over the last 40 years, total fertility rates fell from 6.3 to 2.4, between 1960 and 2000[5], and projections suggest that fertility in Brazil will continue to decline to levels below replacement (Martine, 1996; Wong, 2000; Potter et al. 2002; Goldani, 2002; Silva et al. 2005). The decline of fertility in Brazil is somewhat slower than that in China and Thailand, but it is considerably faster than in Mexico, India, Bangladesh and Indonesia (Martine, 1996). In Brazil, the decline was fastest in the 1970s and 1980s, while the 1990s seem to represent an inflection point[6] in the curves of total fertility rates.

On average, in all Brazilian regions the pattern and pace of reduction has been similar, following a characteristic S-shape curve. The levels, however, have shown significant difference (Graph 1). Historically, the North and Northeast regions have faced

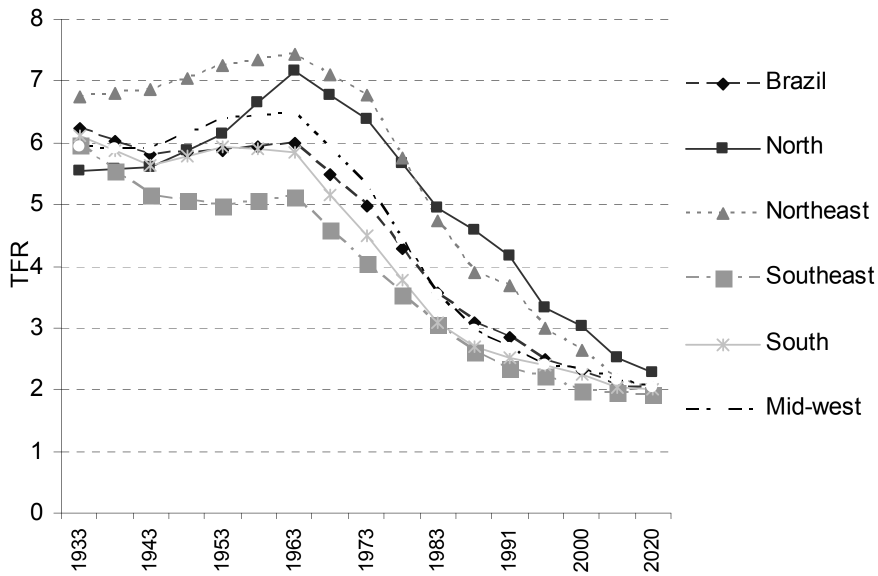
[4] It is hoped that readers will view the material and methods in this study not only in terms of how it can the applied to investigate fertility trends, but also in terms of how it can be extended to their own interests.

[5] The level and decline of fertility is even more evident when tempo effects are taken into account. Silva et al (2005), suggest that "the 'pure quantum component' was already below replacement in 1987, remaining constant around 2 in 1991. Pure fertility declined to 1.74 in 1996, reaching 1.68 in 2000" (Silva et al, 2005: 9).

[6] An inflection point is a point on a curve at which the sign of the curvature (i.e., the concavity) changes. In the case of fertility it can be understood as the period in which the pace of the decline decelerated.

the highest TFRs, while the Southeast has had the lowest. A common explanation for these discrepancies has been the differences in the levels of development of these regions. There is a vast literature pointing to education, income, socioeconomic status, women's labor force participation, declining marital fertility, race and religiosity as causes of the decline and inter-regional differentials of fertility in Brazil (Merrick and Berquó, 1983; Silva, Henriques and Souza, 1990; Lam, Sedlacek, and Duryea, 1992; Wong, 1994; Martine, 1996; Lam and Duryea, 1999; Rios-Neto, 2000). The argument is that the most industrialized and wealthier southern and southeast regions faced favorable socio-economic changes first and were followed years later by the northern and northeastern regions, and this differences, linked to modernization, would help to explain differences in the level and pace of fertility decline between regions (Potter et al. 2002; Berquó and Cavenaghi, 2004).

Graph 1. Total fertility rate, Brazil and regions, 1933- 2020



Source: Horta, Carvalho and Frias (2000), and Wong (2000)

Other explanations to the decline of fertility are the spread of mass communication and media (Hornik and McAnany, 2001) institutional changes in the areas of health and social security, and structural shifts in the economy, which assumedly reinforced the motivation for the effective practice of birth control (Martine, 1996). In the micro level, there is little doubt that income plays a role in determining the number of children women have as it shifts the relative costs of raising children. In the past, especially in rural areas, children started work early and supported their parents in old age, and the children did not cost much to raise. In the 1990s, they attend school for longer periods and cost more to support. In the macro level, however, Martine concludes that "the specific argument that economic pressure is the primary force behind changing reproductive patterns is difficult to validate" (Martine, 1996: 64), especially because fertility decline has persisted even in the presence of dramatic changes in the Brazilian economy.

New methods of birth control, primarily pills and female sterilization deserve special attention in the discussion of fertility decline as they became widely available during the 1970s. Oral contraceptives are still sold over the counter, without prescription. Surgical sterilization, which is practiced in Brazil more than any other country, is typically performed during cesarean deliveries. Such deliveries comprised nearly a third of all deliveries in the 1980s. The Demographic and Health Survey carried out by BEMFAM shows that the number of Brazilian couples opting for sterilization as a means of contraception increased by more than 40 percent during the 1986-96 period. The survey found that 40.1 percent of married women or women living with partners had been sterilized, as compared with 26.9 percent in 1986. In the early 1990s, the use of birth-control pills and female sterilization (tubal ligation) continued to contribute to the fertility decline in Brazil. About 65 percent of Brazilian women used contraceptives, which is comparable with levels in developed countries. Of the women who used some method and were in union, 44 percent were sterilized (BEMFAM, 1997).

Abortion in Brazil is also significant. In the early 1990s, 1.4 million abortions were performed each year, almost all of which were technically illegal. This corresponds to approximately one abortion for every two live births. The only cases in which abortion is not subject to legal sanctions in Brazil are rape and danger to the mother's life, but the law is not enforced effectively. The practice of unsafe clandestine abortions helps to explain why Brazil has the fifth highest maternal mortality rate in Latin America, estimated at 141 deaths per 1,000 births, in contrast to eight in the United States (Library of Congress, 1998).

The increase in the use of contraceptive methods, the spread of mass media, urbanization, and the increase in women's education and labor market participation have affected their preferences for less children, contributing to a continuous decrease in total fertility rates. The connection between these variables and how they influence motivational changes towards fewer children is evident and has received lots of attention in the literature. Fewer studies, however, have investigated the presence and effect of neighborhood effects in the decline. In Brazil, the spatial component of fertility has been deliberately ignored in spite of the considerable number of studies calling attention to the importance of taking into account space (Anselin and Griffith, 1988; Griffith and Anselin, 1990; Anselin and Getis, 1992; Anselin, 1992; Matthews, 2003) and its the relationship with fertility (Loftin and Ward, 1983; Pandit and Bagchi-Sen, 1993; Tolnay, 1995; Guilmoto and Rajan, 2001; Weeks, 2003; Weeks et al. 2000, 2002, 2004). The next section explains why and how spatial effects should be taken into account in fertility studies.

Fertility and Space

Geographers started to acknowledge the influence of space on the human behavior a long time ago (Hagerstrand, 1952, 1967; Brown, 1968; Tobler, 1970). In geography, the settlement, urbanization and migration of populations have always been closely linked to geographic barriers, landscape dynamics and, most important, to distances. Opposed to what happens in classical statistical analysis, where the effect of space is seen as a nuisance and "something to get rid of or controlled for" (Weeks, 2003), in geography, space is in the core of the discipline and represents an object of investigation. Economists have also been paying considerably attention to how spatial correlations can affect social modeling since the 1950s (Griliches, 1957). More recently, the debate around the importance of spatial effects has evolved from speculation to become a consensual regularity. The development of new technologies[7] have eased the task of incorporating space into economic and socio-demographic analyses, and as a consequence the number of studies considering spatial components have increased significantly, specially in demography[8] (Matthews, 2003).

The methodological strategy used to incorporate space into statistical analyses differs from study to study[9]. In the case of fertility, however, a common approach has been to infer the existence of diffusion/ neighborhood effects based on the correlation between the fertility and socioeconomic variables of surrounding areas and individual units of analysis. The idea behind this strategy is to show that changes occurred over time are similar among areas that are closer to each other, and thus consistent with spread of diffusion. Thus, the assumptions underlying the spatial correlation of fertility are that 1) places closer to each other are more likely to influence each other through networks and connections; and that 2) there is fertility diffusion whenever there is a positive correlation with fertility levels prevailing in close surrounding areas.

The first assumption is reasonable because the environmental context, which influences individual actions through the provision of information and behavioral cues, is clearly a function of distance. In places that are closer to each other, it is easier to observe, learn and imitate reproductive practices that are evolutionary better simply because people are more likely to interact with their neighbors. As Weeks et al. (2004: 75) have put it, "people are likely to copy solutions to their problems from neighbors." Distance, therefore, plays an important role as it affects the number of neighbors and consequently the likelihood of interaction between them. The probability of interaction thus is translated as the probability of contact between the teller of the message and the potential receiver. This probability is a function of the distance between them unless water or forest barriers intervene (Brown, 1981: 20).

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[7] Various softwares have been developed to deal with spatial analyses. The toolboxes of ArcGIS 9 (ESRI, Redlands, CA) do a good job with data sets smaller than 4,000 cases. However, the license of the program is expensive. The most popular are GeoDa, and SpaceStat, developed by Dr. Luc Anselin's Spatial Analysis Laboratory (SAL) in the Department of Geography at the University of Illinois, Urbana-Champaign. GWR 3.0.1 is starting to show some appeal (Brunsdon et al. 1996; Charlton et al. 2003). STATA also has modules for spatial analyses and GWR.

[8] "Demographic research is moving inexorably from its long-standing pattern of spatial awareness to an increased appreciation for the value and utility of spatial analysis" (Weeks, 2003).

[9] The techniques for analyzing geographically referenced data range from simple descriptive measures to complex statistical inference (Anselin and Getis, 1992). Nevertheless, the objects of study – distance, area, interaction and location – are usually the same and can be grouped in three broad categories of analysis: 1) description (i.e. "portrayal of spatial patterns associated with events or objects in geographic space"); 2) understanding (i.e. "exploration of spatial relationships in order to gain understanding of the processes shaping observed distributions"); and 3) prediction (i.e. "development of models and methods for the prediction and control of events or objects in geographic space") (Scott and Loyd, 2005: 2).

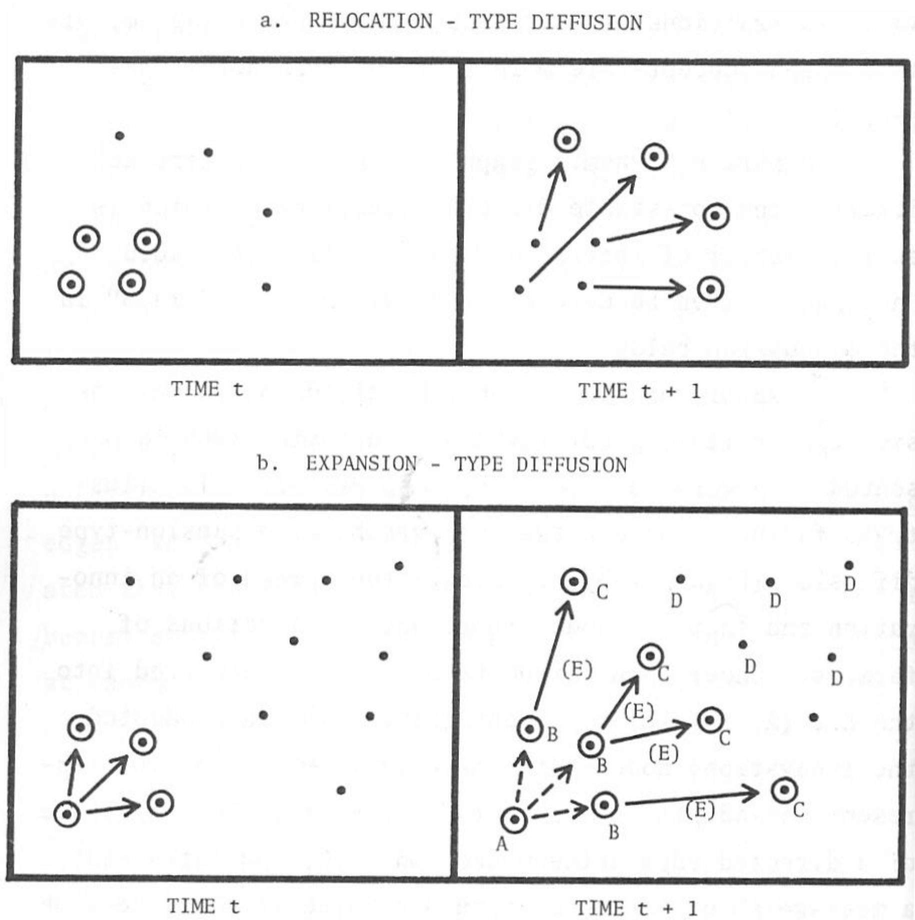
The second assumption – that spatial fertility correlation implies diffusion – is less obvious because it depends on how one defines diffusion. *Lato sensu*, spatial diffusion can be understood as "the spread of a phenomenon within a given area through time" (Brown, 1968: 87) or, alternatively, as "the tendency for what happens in one spatial unit (or geographic area) to influence what happens in others" (Tolnay, 1995: 301). In his early study on general diffusion processes, Brown (1968: 87-88) elaborated the concept further. He noted that every spatial diffusion situation contains six basic elements: "(1) an area or environment and (2) time, which together contain (3) an item being diffused, (4) origin places, (5) destination places, and (6) paths of movement, influence or relationship between origin places and destination places." The first five conditions are compatible with a framework of fertility diffusion in which places with lower fertility are origins and surrounding areas with higher fertility are destinations[10]. The sixth condition, however, is partially undetermined and has received little attention by the literature on fertility.

Spatial analyses of fertility usually establish the "relationship between origin and destination places" as a single function of distance, or contiguity. The distance determines the area and the degree (i.e. the number of neighbors) of the network. Less can be said, however, about the "paths of movement," and the type of influence, between origin and destination. As Tolnay (1995: 302) has put it, "diffusion effects due to the spread of knowledge about birth control cannot be distinguished from those due to the spread of new norms and values about fertility. Similarly, the vehicle of the observed diffusion effect, whether through person-to-person communication within social networks or through more formal channels, cannot be distinguished."

Brown (1968, 1981) also identified two mechanisms through which diffusion can happen. In the first, which he named "relocation-type", members change their location from one point to another over time. One demographic example of this type of diffusion could be a family of migrants moving from south to north (Figure 1a). In the second type of diffusion, new members are added to the population between time *t* and *t+1* and locate in such a way that alters the pattern distribution of the population as a whole. This diffusion, which Brown named "expansion-type," is characterized by associative transfer in which an event occurring in one place gives rise to or is correlated with an event occurring later in another place (Figure 1b).

Figure 1. Two types of diffusion portrayed as dynamic graphs

[10] The inverse logic could also be applied in this diffusion framework. A situation in which the origin has higher fertility than the destination nodes is also possible, although unlikely.



• Indicates a potential location of the diffusing phenomenon.

⊙ Indicates an actual location of the diffusing phenomenon during the time indicated.

•⟶• Indicates that during the indicated time a stimulus passes from the node at the origin end of the arrow to the node at the destination end, and results in location of the diffusing phenomenon at the destination node.

•- -➤• Indicates that the stimulus represented in •⟶• passes during a time period previous to the one indicated.

Source: Brown (1968: 12)

The dynamics of fertility is better represented by the expansion-type diffusion. In this case, nodes (A), (B) and (C) represent municipalities that made the transition from high to low levels of fertility in time *t+1*, and nodes (D), which are not connected in the network , are municipalities where fertility have not suffered the influence of neighboring localities. Nodes (D), however, represent potential adopters of lower fertility in times succeeding *t+1*.

In this study I consider that the diffusion of fertility follows an expansionary pattern. Similar to what has been done in other spatial studies, I hold that individual fertility in municipality *m* influences and is under the influence of the neighboring network defined within distance *d*. Although it is hard to sort out how much of the change in fertility behavior is due to diffusion mechanisms and how much is due to changes in the socioeconomic factors of the network induced by diffusion itself (Palloni, 2001: 96), this study attempts to separate these two influences in a cross-sectional perspective that takes into account spatial heterogeneities via local estimators. Other intrinsic difficulties of diffusion processes, such as the mobility of agents[11], the identification of the source, and the direction and speed of diffusion, are not explicitly considered here. Although this study represents an improvement over previous ones (Potter et al. 2002) by dealing with spatial autocorrelation and spatial heterogeneities, it is only a first step to understand how and why diffusion happens[12]. As a corollary, this study yields only indirect evidence of diffusion processes.

DATA

To investigate the influence of socio-economic and spatial factors on fertility trends in Brazil I use the 2000 Brazilian Atlas of Human Development produced by the UNDP, IPEA and Fundação João Pinheiro. This software is based on the last two Brazilian censuses and has socio-demographic information for all municipalities in 1991 and 2000. The Atlas covers five broad dimensions: education, income, demography, habitation, and vulnerability. The main advantage of the Atlas is that it is publicly available[13], and provides comparable socio-demographic information for all municipalities[14] in Brazil over the decade, despite the changes in municipal boundaries between 1910 and 1920[15].

Previous studies of fertility in Brazil have used an aggregation of *microregions*[16] to obtain "*minimum comparable areas*" (Potter et al. 2002: 742). With this type of procedure the authors obtained 518 spatial units comparable across four censuses – 1960, 1970, 1980, and 1991. The drawback of this type of aggregation, however, is that observable regional heterogeneities are lost in the analysis. This is problematic because the social and economic contexts influencing fertility varies from place to place, and with more aggregated areas local variations in the relationship are lost. With a few exceptions

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[11] Although migration is not explicitly considered in the analysis, I added a variable in the models to capture the effect of out-migration at reproductive ages.
[12] Recent efforts are being done to measure the timing and pace of fertility decline in Brazil using a Bayesian spatial estimation procedure (Potter et al., unpublished manuscript).
[13] The Atlas of Human Development is available, in Portuguese, on line at http://www.pnud.org.br/atlas/
[14] Municipalities are similar to counties in the U.S.. The difference is that their boundaries are less stable over time. In municipalities with very small populations – with less than 30,000 people – the socio-demographic variables tend to be unstable due to sampling variability. To solve this problem, the indicators were smoothed using regression analysis. The principle of this technique is to obtain a new estimator representing a weighted average of the observed (x) and estimated (x') values using regression analysis. With this method, when the population is relatively large, the new estimator will be equal to the observed value (x), and when the population is small, the value of the new estimator will be close to the value (x') estimated in the regression. The specificities of the municipalities and micro-regions were considered in the regression analysis.
[15] Between 1991 and 2000, the number of Brazilian municipalities increased from 4,491 to 5,507. To allow comparisons between these two periods, the municipal boundaries of 2000 were reproduced in 1991 through the rearrangement of census tracts. Only 1.5 percent of the census tracts (2,379/ 161,697) presented problems during the matching process between 1991 and 2000. From a global perspective this represents a small proportion of the country.
[16] Microregions are groups of municipalities. In Brazil, geographic units are aggregated in the following ascendant order: census tracts, municipalities, microregions, macroregions, states, and regions.

(Tolnay, 1995; Weeks et al. 2000, 2002, 2004), most studies examining fertility by regions do so on the basis of rural-urban dichotomies, as if there was uniformity of fertility within these areas. As Weeks (2003) has noted, the literature has not given attention to the social causes and consequences of fertility trends at the local level. Rather, the emphasis in the literature has been on examining fertility variations in the individual level, using data that do not permit a neighborhood analysis, or in cross country comparisons, which loose important inter and intra regional variations.

The size and diversity of Brazil in terms of economy, geography, demography and culture demand analyses that take into account inter and intraregional differences. In this sense, municipal indicators are important to demonstrate these differences and to point directions to governments, community leaders, politicians, researchers and the press. For these reasons, all the 5,507 Brazilian municipalities are used in the analysis that follows.

Variables

The main variable of interest is the municipal total fertility rate (TFR). This variable is promptly available in the Atlas of Human Development but its calculation deserves some explanation because usually small areas tend to have small risk populations which produce unstable estimates because of sampling variability (Freire and Assunção, 1998; Assunção et al. 2002, 2005). Renato Assunção and others have proposed the use of Bayesian methods to estimate these rates, but a much simpler approach using indirect fertility methods provide consistent results with *demographic plausibility* and *regional accuracy*.

The TFRs in this study were estimated using and adaptation of the Brass method of indirect fertility (Brass et al. 1968) suggested by Horta et al. (2004). In all municipalities with less than 30,000 people[17], the level of age specific fertility rates were corrected using adjustment factors that take into account the parity of neighboring municipalities located in the same microregion. Using the parity information of small municipalities $(P_{i,t}{}^{m})$ and of the microregion of reference $(P_{i,t}{}^{s})$ it is possible to establish a relation (k, t^{m}) between these two geographic levels:

$$k_t{}^m = P^m_{i,t} \Big/ P^s_{i,t} \qquad \textbf{(1)}$$

where P_i^m is the parity of women in age group i and municipality m; P_i^s is the parity of women in age group i and reference group (microregion) s; i indexes the age group of the mother (20-24, 25-29, or 30-34 years old); t indexes the year (1991 or 2000); and k, t^{m} indicates the differential in the level of fertility between municipality m and microregion s.

Specific fertility rates for age i, municipality m, and year t are then estimated by:

[17] In 2000, about 48 percent (2,643) of the municipalities had populations under 10,000 people.

$$\overline{ASFR_{i,t}^{m}} = k_t^m * \overline{ASFR_{i,t}^{s}} \qquad \textbf{(2)}$$

where $\overline{ASFR_{i,t}^{s}}$ is the age specific fertility rate of the microregion of reference *s* estimated using the Brass method of indirect fertility. Total fertility rates for each municipality are then obtained by summing $\overline{ASFR_{i,t}^{m}}$ over age groups *i* and then multiplying the result by the size of the age interval, which in this case is equal to five years:

$$\overline{TFR_t^m} = 5 * \sum_{i=15}^{49} \overline{ASFR_{i,t}^{m}} \qquad \textbf{(3)}$$

The covariates in the models include child mortality, index of education, urbanization rate, female labor force participation (in 2000), and percent of households with television[18]. These variables have been used in previous studies as "conventional socioeconomic indicators" (Bongaarts and Watkins, 1996; Potter et al. 2002). The novelty variables are the sex ratio of people older than age 15, the percent of whites, and the fertility of surrounding areas, which will be responsible for indicating the presence of neighborhood effects. These variables have been employed in recent studies taking into account the role of space (Loftin and Ward, 1983; Pandit and Bagchi-Sen, 1993; Tolnay, 1995; Guilmoto and Rajan, 2001; Weeks, 2003; Weeks et al. 2000, 2002, 2004).

Child mortality[19] is in the model for two reasons. First, because fertility is expected to be higher where couples are induced to bear excess children in anticipation to mortality; and second, because in places with high child mortality there may be an incentive to replace lost children (Tolnay, 1995: 303). Thus, child mortality is expected to be positively correlated with total fertility rates.

The "index of education" prevailing in the *município* in 1991 or 2000 is included in the models to capture the negative relationship with fertility. Higher levels of parental education are associated with the grater use of birth control and lowered marital fertility (Cleland and Wilson, 1987). Education needs also increase the cost of children and decrease their economic value to the family. Educated parents are expected to desire fewer children than their educated neighbors (Tolnay, 1995: 303). The index of education

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[18] Child mortality, level of education and percent of households with television were highly multicollinear. In the presence of multicollinearity, the standard errors of the estimated coefficients are likely to be very large (reflecting that there is not enough independent variation in a variable to calculate its effect with confidence). This is problematic for two reasons. First because the individual P values can be misleading (a P value can be high, even though the variable is important); and second, because the confidence intervals on the regression coefficients will be very wide. Multicollinearity, however, is not a problem for the predictions or for the coefficients of determination (R^2 or adjusted R^2). In this study the impact of multicollinearity is reduced by the large sample size. Despite the multicollinearity between child mortality, level of education and percent of households with television, all variables were statistically significant in the global models.

[19] Child mortality refers to the number of children that will survive to their first year of life – in every 1,000 children born alive.

used in this study varies between 0 and 100 and is built as a weighted average of literacy rates, with weight 2/3, and enrollment rates, with weight 1/3[20]. Nevertheless, as Martine (1986: 63) noticed that is "highly unlikely that the improvements in education" would alter fertility patterns by itself, I also consider the influence of other relevant variables.

The urbanization rate is included to capture the fact that in more urbanized areas the expenditure with children tends to be higher while their economic value tends to be lower. In urban areas the use of contraception also tends to be higher than in rural areas. The expected sign for this variable is negative.

Female labor force participation (in 2000)[21] is a well-known correlate of lower fertility. It represents the opportunity cost between childbearing and professional career. Improving the status of women through education and employment overthrows the traditional female role within the family. Increasing female labor force participation represents the trade off between women empowerment and fertility reduction (Cohen, 1995: 71). I expect fertility to be negatively correlated with this variable, although Martine (1996: 63) has pointed that the effect of labor force participation "has been ambiguous."

The percent of households with television is in the models to catch the penetration of the media into each municipality. The media represents an influence for the diffusion of new information and ideas and is a variable that has had significant impact in similar Brazilian fertility studies (Faria, 1989; Faria and Potter, 1999; Potter et al. 2002; Rios-Neto, 1987, 2001). While studying the factors behind the fast decline of fertility in Kenya, Cohen (1995: 66) asserted that "(…) a very successful soap opera, heard by 41 percent of the population, extolled the advantages of limiting family size. Exposure to such messages through the media was strongly associated with preferences for smaller families and with the use of contraception."

The sex ratio of people older than 15 years represents a proxy for the effect of out-migration at reproductive ages. Since in most municipalities men are more likely to emigrate than women, the adult sex ratio indicates the importance of male migration to fertility in the local community. A high ratio indicates relative high male in-migration, whereas a low ratio would be suggestive of male out-migration, which is usually

[20] To obtain the index of education for municipality *i* I employ two measures of education: the adult literacy rate *Ai* and the enrollment rate *Mi*. These two variables are first transformed into indexes using 0% and 100% as limit values:

$$\text{Index of adult literacy} = IA_i = \frac{A_i - 100}{100 - 0} = \frac{A_i}{100}\text{; and Index of enrollment} = IM_i = \frac{M_i - 100}{100 - 0} = \frac{M_i}{100}$$

$$\text{So combining these two indexes and applying the respective weights it comes: Index of education} = IE_i = \frac{2IA_i + IM_i}{3}$$

[21] "Female labor force participation" refers to the percent of women who were working or searching for work in the week of reference preceding the census. This variable is available on line at [http://www.ipeadata.gov.br/]. The information collected in 1991 is not comparable to 2000 and therefore is not considered in this analysis. In 1991, female labor force participation refers to women who were working or searching for work in the last 12 months, rather than in the last week.

expected in more urbanized areas (Weeks et al. 2002: 9). The sex ratio at reproductive ages is an indicator of environmental context. I expect it to have a positive relationship with fertility.

The percent of whites is included to capture the fertility differentials between racial groups. In Brazil, whites have been observed to have lower total fertility rates than non-whites (Berquó and Cavenaghi, 2004) – although this relationship may be confounded by socioeconomic effects (Pandit and Bagchi-Sen, 1993: 234).

The last covariate employed in the analyses is the fertility of surrounding areas. The sign, size and significance of the coefficient attributable to this variable shows the extent to which changes in fertility at the local level may influence, and be influenced by, changes in other neighboring regions. If proximity matters, then the fertility of each municipality will be spatially dependent from the fertility prevailing in surrounding regions. According to Tolnay (1995: 301), “if Area A is proximate to areas with relatively low fertility, and Area B is surrounded by areas with high fertility, Area A will have lower fertility than Area B.”

Table 1. Descriptive statistics for demographic data of Brazil, 1991 and 2000

Variable	Mean	Median	SD	Min	Max	Skewness*	N
TFR							
1991	3.74	3.41	1.24	1.76	8.68	0.95	5504
2000	2.86	2.67	0.74	1.56	7.79	1.47	5505
Child mortality							
1991	49.45	42.83	25.00	10.65	130.74	0.71	5504
2000	34.08	29.51	18.47	5.38	109.67	0.72	5505
Index of Education (%)							
1991	0.64	0.68	0.14	0.12	0.92	-0.57	5504
2000	0.78	0.80	0.09	0.43	0.98	-0.52	5505
Female labor force participation							
1991	-	-	-	-	-	-	-
2000	0.35	0.35	0.05	0.15	0.51	-0.37	5505
Urbanization rate (%)							
1991	49.61	48.85	25.93	0.00	100.00	-0.02	5504
2000	58.82	59.33	23.33	0.00	100.00	-0.10	5505
Households with TV (%)							
1991	49.26	48.75	27.67	0.00	97.51	-0.02	5504
2000	75.01	81.78	20.34	6.24	99.54	-0.98	5505
Sex ratio at reproductive ages							
1991	1.04	1.03	0.09	0.76	2.20	1.52	5504
2000	1.03	1.02	0.08	0.82	1.72	0.99	5505
White population (%)							
1991	50.11	47.70	27.91	0.03	100.00	0.12	5504
2000	52.54	49.64	25.52	0.71	100.00	0.15	5505
TFR of near neighbors							
1991	3.70	3.38	1.06	0.00	8.29	0.55	5504
2000	2.83	2.66	0.62	0.00	7.28	0.76	5505

* Skewness measures the degree and direction of asymmetry. A symmetric distribution such as a normal distribution has a skewness of 0, and a distribution that is skewed to the left has a negative skewness.
Source: 1991 and 2000 Brazilian Censuses

Table 1 provides descriptive statistics for the variables employed in the models. It shows that the total fertility rate declined, on average, 23 percent between 1991 and 2000[22]. The independent variables, the proximate socioeconomic determinants of fertility, also showed improvement over the decade. The percentage of households with television, in particular, increased 52 percent, while child mortality decreased 31 percent during the decade. The TFRs of near neighbors – which theoretically accounts for the "neighborhood effects" of fertility – is calculated as the average TFR of municipalities

[22] This decline is relevant but smaller than the one observed in the previous decade – 1980 to 1991 – when fertility declined by 40 percent according to the census bureau.

surrounding individual units of analysis within a "critical distance"[23]. The minimum values of this variable are equal to zero because some municipalities in the Northern region of Brazil (i.e. Amazon) do not have neighbors within the defined critical distance.

METHODS

The first part of this section describes the methodological strategy adopted to identify the "hot/ cold spots" of fertility, that is, it describes the spatial methods used to study the spatial clustering of overall fertility rates for each decade among all Brazilian municipalities.

The second part of this section describes the idea behind geographically weighted regression (GWR) techniques. It states why this approach may be particularly better than other spatial analysis methodologies and discuss a potential drawback of the method.

Critical distance and indicators of spatial autocorrelation

I empirically define the critical distance as the value that maximizes the spatial correlation of fertility between municipalities in 1991 and 2000. The level of spatial correlation is indicated by the commonly used Moran's *I* statistic[24], which in this case can be expressed as

$$I_t = \frac{\sum_{i=m}^{N} \sum_{j=1, j \neq m}^{N} w_{m,j} * \left(\overline{TFR_t^m} - \overline{\overline{TFR_t}} \right) * \left(\overline{TFR_t^j} - \overline{\overline{TFR_t}} \right)}{\sum_{i=1}^{N} \left(\overline{TFR_t^m} - \overline{\overline{TFR_t}} \right)^2}, \quad \textbf{(4)}$$

where $w_{m,j}$ is an element of a row-standardized spatial weights matrix based on fixed distances[25], $\overline{TFR_t^m}$ and $\overline{TFR_t^j}$ are estimated total fertility rates for observations *m* and *j* $(m \neq j)$, $\overline{\overline{TFR_t}}$ is the average total fertility rate in year *t*, and *m* and *j* index municipalities 1, 2… 5,505 (Anselin, 1988). When I_t is positive and significantly different from zero, observations with high (low) values are close to one another. When I_t is negative, high values are located near low values. In 1991, 105 kilometers was the fixed distance giving

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[23] The critical distance is the value of the radius *d* used to define the scope of the area within which surrounding municipalities are considered neighbors. The neighborhood effect, therefore, occurs only if the distance between individual municipalities and surrounding areas is equal or less than some value *d*, and within the range of *d* all municipalities have equiprobability of connection. The methodological section describes the empirical procedure used to define the critical distance.

[24] High spatial autocorrelation occurs when TFRs in a specific municipality covary with those of municipalities that are contiguous to it within the critical distance. If there is a little relationship between TFRs in a given municipality and that of its neighbors, this fact will be reflected in a low Moran's *I*.

[25] The weights matrix can also be defined using different types (Queen, Rook) and orders (first, second, etc.) of adjacency. In the case of fertility, however, fixed distances are more appropriate than adjacency. I do not expect the fertility of far, but adjacent neighbors, to influence the reproductive behavior of the neighboring municipalities. In the Amazon, for instance, where the municipal centroids are farther from each other, I expect to have a weaker relationship between neighboring areas, and this weaker relationship can only be imposed using a fixed critical distance.

the highest global spatial correlation of fertility (Moran's $I = 0.687$). In 2000 the critical distance changed to 100 kilometers and the global spatial correlation decreased to 0.607.

A better way to visualize the spatial correlation of fertility, however, is to map the four quadrants of the Moran scatter plot (Anselin, 1996) using Local Indicators of Spatial Association (LISA) statistics (Anselin, 1995). This approach allows one to identify whether municipalities with above (below) average fertility cluster in neighborhoods with above (below) average values – positive spatial relationship. Similarly, LISA maps also help to locate above (below) average observations placed in neighborhoods with below (above) average fertility – relationships that contribute to negative Moran's *I* (Johnson et al. 2005: 796). In the analysis that follows, I use municipal LISA maps to identify the areas of Brazil in which fertility is clustered, that is, regions where municipalities have similar fertility rates.

Geographically Weighted Regression

Geographically weighted regression (GWR) models are more appropriate than standard global linear models (i.e. OLS) whenever the relationship between dependent and independent variables is uneven, rather than stationary, across space. Algebraically, a global regression model for fertility can be expressed as

$$V\left(\overline{TFR_t^{\,m}}\right) = f\left(S_t, N_t\right) + \varepsilon_t \qquad \textbf{(5)}$$

where $V\left(\overline{TFR_t^{\,m}}\right)$ is a vector containing TFRs for municipalities *m* in year *t*, $f(S_t, N_t)$ is a functional form with socioeconomic (*S*) and neighborhood fertility, and ε_t is the residual term. In a global analysis, what is undertaken is the generation of an "average" set of results from the data. If the relationship varies across the study region, the global results will have limited application to specific parts of that region and may not, in fact, represent the actual situation in any part of it (Fotheringham and Brunson, 1999: 341). Within the framework of GWR, the model expressed in equation (5) can be re-written as:

$$V_i\left(\overline{TFR_t^{\,m}}\right) = f_{\mathrm{i}}\left(S_t, N_t\right) + \varepsilon_{t,i} \qquad \textbf{(6)}$$

where the subscript *i* represents specific geographical locations. GWR, therefore, extends the traditional regression framework of equation (5) by allowing local rather than global parameters to be estimated (Brunsdon et al. 1996; Fotheringham et al. 2002). In essence, as Fotheringham and Brunsdon (1999: 348) have put it, equation (6) "measures the relationships inherent in the model *around each point i*."

In particular, the three models estimated in this study can be specified in the following linear form:

$$\ln\left(\overline{TFR^{m}_{1991,i}}\right) = a_{0i} + a_{1i}C\_MORT91 + a_{2i}PPTV91 + a_{3i}SR\_15\_91 + a_{4i}URBRATE\_91 + a_{5i}HDI\_EDU91 + a_{6i}WHITE91 + a_{7i}NEAR\_TFR + \varepsilon_{1991,i} \quad \textbf{(7)}$$

$$\ln\left(\overline{TFR^{m}_{2000,i}}\right) = b_{0i} + b_{1i}C\_MORT00 + b_{2i}PPTV00 + b_{3i}SR\_15\_00 + \mathrm{b}_{4i}URBRATE\_00 + b_{5i}HDI\_EDU00 + b_{6i}WHITE00 + \mathrm{b}_{7i}NEAR\_TFR00 + b_{8i}FLF + \varepsilon_{2000,i} \quad \textbf{(8)}$$

$$\Delta\left(\overline{TFR^{m}_{i}}\right) = c_{0i} + c_{1i}\Delta C\_MORT + c_{2i}\Delta PPTV + c_{3i}\Delta HDI\_EDU + c_{4i}\overline{TFR^{m}_{1991,i}} + \varepsilon_{i} \quad \textbf{(9)}$$

Each term on the right-hand side of equation.(9) represents the predicted effect of observed changes in one indicator, holding others constant. Thus Δ refers to the difference between 1991 and 2000 values, *i* indexes point observations and

1. $\ln\left(\overline{TFR^{m}_{i}}\right)^{*}$	Natural logarithm of the estimated municipal TFR
2. C_MORT	Child mortality in every 1,000 children
3. PPTV	Percent of households with TV
4. SR_15_19	Sex ratio (males/ females) at reproductive ages
5. URBRATE	Urbanization rate
6. HDI_EDU	Index of education
7. WHITE	Percent of white population
8. NEAR_TFR	Average TFR of neighboring municipalities
9. FLF	Female labor force participation in 2000

* I use the natural logarithm to improve the linearization with the independent variables. Appendix 1 and 2 show scatter plots between dependent and independent variables to confirm that the relationship is indeed linear.

Equations (7) and (8) describe contemporaneous relationships between fertility and relevant socioeconomic variables, and equation (9) describes how changes in fertility over the decade are influenced by changes in basic indicators. In previous study, Potter et al. (2002) made an attempt to model fertility in Brazil, but their methodological approach did not consider the spatial component of fertility nor the differential effect of socioeconomic heterogeneities across space[26]. Moreover, the authors also neglected the importance of the lagged number of births while "predicting changes in fertility." As Weeks et al. (2002: 19) have put it, the fertility level prevailing in the past must be included as an endogenous variable since "the absolute amount of decline is at least in

[26] Potter at al. (2002: 752) use a linear fixed effects model that assumes constant cross-sectional slopes and varying intercepts. In their words, their model "assumes that coefficients (and therefore the effects of changes in indicators) are identical in all regions and periods, but they may differ between urban and rural zones." The authors also recognize the limitation of the paper in dealing with spatial autocorrelation.

part dependent upon how high fertility level was to start with." The methodological approach adopted here, therefore, improves previous estimation procedures by taking into account spatial local correlations and the lagged level of fertility in 1991. The places in which it was highest in 1991 were the municipalities to experience the largest drop in the average number of births.

In the calibration of GWRs, points closer to *i* have more influence in the estimation of the coefficients than data located farther from *i*. Observations are weighted according to their proximity to point *i* so that the weighting in the calibration varies with *i*. The weights – used to ensure that near locations impose more influence on the calibration than locations farther away – are usually obtained through a spatial kernel (bandwidth) function[27], which determines the number of local points that will be included in each local regression. In this study I use an adaptive kernel function to ensure a constant size of local samples[28, 29]. The GWR for 1991 and for the change of fertility (equation 9) used a local sample size equal to 283 points. In 2000, the sample size increased to 442 municipalities.

The bandwidth providing the optimum size of nearest neighbors for the adaptive kernel is determined by the Akaike Information Criterion (AIC) minimization. Following Hurvich et al. (1998), the AIC of a GWR model is defined as

$$AIC = 2n\ln(\hat{\sigma}) + n\ln(2\pi) + n\left[\frac{n + tr(S)}{n - 2 - tr(S)}\right] \qquad \textbf{(10)}$$

[27] There are two types of spatial kernel: fixed and adaptive. In a fixed kernel, the observations used in the regression are those within a fixed bandwidth provided by the researcher. This approach is less computationally intensive, but can produce large local estimation of the variance in areas where data are sparse, and may mask subtle local variations in areas where data are dense. The dilemma faced by the researcher when using fixed kernels is to make a decision in the trade off between bias and standard error. On the one hand, the smaller the bandwidth, the more variance but the lower the bias; on the other hand, the larger the bandwidth, the more bias but the more variance is reduced. This is because larger bandwidths imply in fewer estimated betas over space, and thus more similar to a global regression, which means more biased results (Fotheringham et al. 2002). Alternatively, the adaptive kernel function seeks a fixed number of nearest neighbors to ensure that local samples will keep a constant size. The number of neighbors in the adaptive kernel is given by the AIC minimization, which provides a way of choosing bandwidth that makes optimal tradeoff between bias and variance.

[28] Adaptive kernels are particularly appropriate in the case of Brazil, where the data is not evenly distributed. Adaptive kernels represent weighting functions that can adapt themselves to varying density of data points over space when the data do not have uniform density (Fotheringham and Brunsdon, 1999). The adaptive kernel also presents more reasonable means in representing the degree of spatial non-stationarity in the study area (Yu, 2004: 4).

[29] There is a cautionary tale here regarding the level of multicollinearity in local parameters estimates. Wheeler and Tiefelsdorf (2005: 184) claim that "In GWR, moderate to strong correlation of two explanatory variables makes their associated local parameters almost completely interdependent. This correlation of local regression coefficients potentially invalidates any interpretation of individual GWR parameters estimates and can facilitate misleading conclusions if the situation is not properly diagnosed." Post estimation residual analysis, goodness of fit statistics and the low correlation between estimated parameters indicate, however, that linear GWRs performed adequately.

where n is the sample size, $\hat{\sigma}$ is the estimated standard deviation of the error term, and $tr(S)$ denotes the trace of the hat matrix S of the GWR, which is expressed as

$$\hat{y} = Sy \tag{11}$$

where y and $\hat{y}$ are the vector of the dependent variable and the GWR estimated values, respectively. An important advantage of the AIC is to provide a criterion of comparison to assess whether GWR provides a better fit than a global model taking into account the different degrees of freedom in the two models.

The GWR software package, GWR 3.0, used to implement the models also provides a Monte Carlo test to investigate the spatial non-stationarity of the relationships between dependent and independent variables. This test is based on the sample variance of the estimated model coefficients (Brunsdon et al. 1996; Leung et al. 2000) and shows whether the effect of covariates in a local model is statistically different from the effect in a global, and more parsimonious, model[30].

Clustering of fertility

Figure 2 presents the geographic patterns of fertility and its spatial correlation illustrated in LISA maps. The figure reveals that the Northeast and some parts of the Northern region experienced consistent high fertility in 1991 and 2000, while most of the Southeast and southern region experienced low fertility that is spatially clustered[31]. Over the 1990s, the number of clusters with high and low fertility contracted, such as demonstrated by the relatively lower Moran's I in 2000 (0.61). The proportion of "high- high" fertility clusters remarkably diminished in the Northeast, predominantly in the states of Bahia and in parts of Piauí, Ceará and Maranhão. In particular, municipalities surrounding Salvador, the capital of Bahia, formed a cluster with high, spatially correlated, fertility in 2000.

The northeastern region is more rural and has consistently been characterized by higher child mortality, and lower levels of per capita income, education and electrification. All these characteristics are certainly are also associated with more traditional attitudes and behaviors and have undoubtedly contributed to the higher levels of fertility in the region.

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[30] This test in described in Fotheringham (2002: 93).

[31] The map in the appendix depicts the location of the Brazilian regions and states.

Figure 2. Total Fertility Rates and Local Indicators of Spatial Association (LISA) Maps

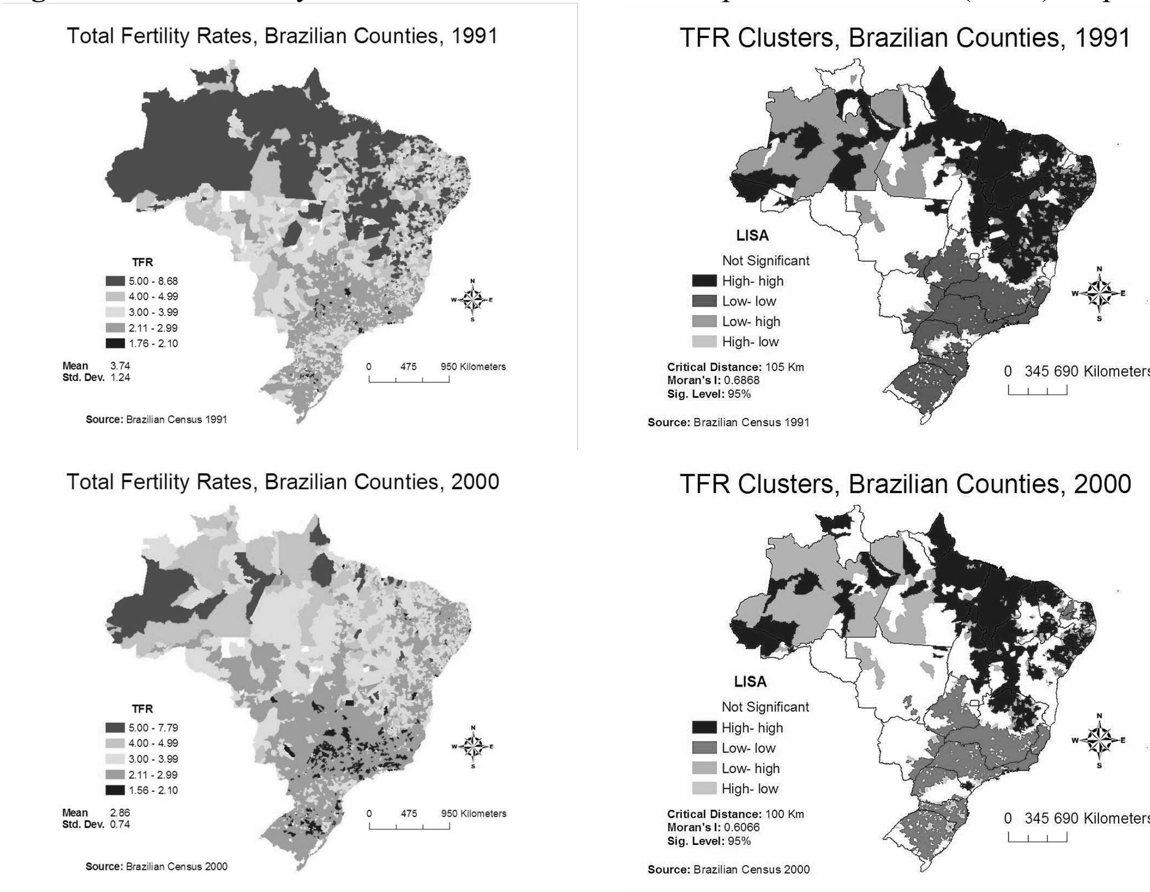
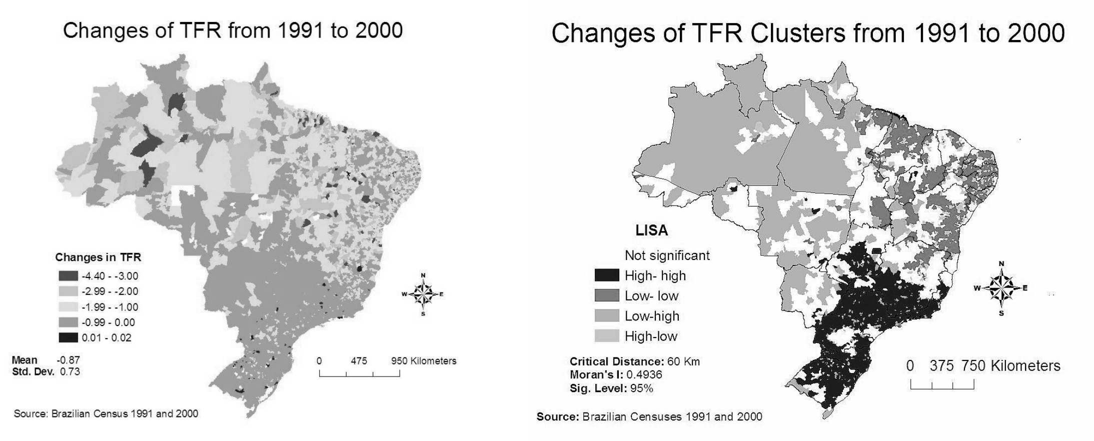


Figure 3 shows the difference between TFRs in 2000 and 1991. More negative values, therefore, represent places where fertility declined the most, and values close to zero occurred in places where fertility had little change. The figure provides evidence that municipalities clustered among high fertility locations are the places where the greatest decline in fertility occurred. The map on the right, in particular, shows that the decline between 1991 and 2000 had a clear spatial component to it.

Figure 3. Changes in Total Fertility Rates and Spatial autocorrelation of Changes



Looking at these descriptive maps, the questions that naturally emerge are**:** What are the factors accounting for these patterns and how are they related to fertility changes? In other words, what explains the temporal-spatial pattern of fertility? The next section investigates the influence of socioeconomic and spatial variables over total fertility rates.

Development or Diffusion?

To investigate the role of socioeconomic factors vis-à-vis the spatial component of fertility I estimate global regressions taking into account the spatial dependence of the errors[32] – i.e. the error of an observation affects the errors of its neighbors [33]. Table 2 reports the estimated results.

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[32] The diagnostic tests for spatial dependence were positive, indicating that classic OLS models can improve their efficiency and fit with a spatial error model. Indeed, the R^2 and the Akaike Info. Criterion statistics suggest that the OLS model with spatial error has a better fit than the classic OLS. The alternative model accounting for spatial correlation, OLS with spatial lags, did not perform as good as the OLS with spatial errors.

[33] With spatial error in OLS regression, the assumption of uncorrelated error terms is violated. As a consequence, the estimates are inefficient. The presence of spatial error is an indicative of omitted (spatially correlated) covariates that if left unattended would affect inference. OLS with spatially correlated errors can be understood as a particular case of the classic OLS regression – $y_i = x_i^t \beta + \varepsilon_i$ – where $\varepsilon_i = \lambda W_\varepsilon + \xi$ and LAMBDA (λ) is a coefficient accounting for spatially correlated errors.

Table 2. OLS (with spatially correlated errors) coefficients for ln (TFR)

	1991		2000		
	Model 1	Model 2	Model 3	Model 4	P-value*
Constant	1.415	1.599	1.537	1.686	0.00
Child Mortality	0.002	0.002	0.002	0.002	0.00
Percent of hh. w/ TV	-0.004	-0.004	-0.003	-0.003	0.00
Sex ratio	0.339	0.305	0.356	0.321	0.00
Urb. Rate	0.001	0.001	0.001	0.001	0.00
Index of Education	-0.501	-0.504	-0.712	-0.720	0.00
Percent of whites	-0.002	-0.002	-0.002	-0.002	0.00
LAMBDA	0.851	0.898	0.857	0.881	0.00
Female Labor F. P.	-	-	-0.153	-0.174	0.00
TFR of near neighbors		-0.048		-0.049	0.00
R^2	0.807	0.811	0.732	0.736	
Akaike info criterion	-5896.82	-5942.43	-7216.39	-7257.76	
Br-Pagan test prob.	0.00	0.00	0.00	0.00	

* All variables, in all models, were highly significant (P-value< 0.001).

The signal of the coefficients in models 1 and 3 were expected and are consistent with what have been reported in literature. The value of LAMBDA demonstrates that the error terms across different spatial units are correlated and have a positive and strong effect on fertility. Surprisingly, table 2 also shows that the average fertility of near neighbors (models 2 and 3) have little effect on the impact of other variables and is negatively associated with municipal TFRs. For instance, for every increase of one child in the average TFR of neighboring places, the natural log of the municipal TFR decreased by 0.048 – i.e. a 4.8 percent decline – in 1991 and 0.049 in 2000. This result is counterintuitive and suggests that, *ceteris paribus*, once the spatial correlation of the errors is taken into account, the positive effect of the fertility prevailing in surrounding areas is washed out and turns out to be negative. This result, therefore, provides evidence to reject the hypothesis of fertility diffusion, although it does not reject the hypothesis that non-observable heterogeneities prevailing in the surrounding areas– such as captured by the LAMBDA term – may play a role in the decline of fertility. It is, in fact, likely that the positive effect of the TFR of near neighbors, observed in the absence of the spatial error term[34], were masking the effect of socioeconomic characteristics of bordering municipalities. This would explain the reversal of the sign of the "TFR of near neighbors" once LAMBDA is added to the model. In sum, if there are diffusion processes affecting fertility transition, they seem to be more related to the non-observable characteristics (i.e. socioeconomic factors) of surrounding municipalities than to their total fertility rates.

Over the decade, the association between fertility, structural socioeconomic indicators, and space changed very little. Only the index of education significantly

[34] The positive relationship between municipal and neighboring TFRs can be observed in the scatter plot depicted in the first two appendices.

changed its effect. In 1991, a one percent increase in the index of education was associated with a decline of 50 percent in total fertility rates and, in 2000, with a reduction of 72 percent. It is also worth noting that, although the effect of most variables remained virtually the same over the decade, the percentage of the variance in TFRs "explained" by the model diminished, such as reported by the decline in the coefficients of determination[35].

An alternative way of examining the impact of these variables over time is to estimate models of the change of fertility between 1991 and 2000 to see if the change in the significant predictor variables discussed above can explain the change in fertility over the decade. Table 3 shows that the decline in child mortality and the increase in the number of households with TV contributed very little to the decline of fertility. The correlation of these two variables with fertility remained virtually the same over the decade (Table 2), and their changes also demonstrate little effect on changes in the average number of children that women were having. Model 7 also suggests that the average decline of 0.87 children in the TFR of near neighbors helped to slowdown the decline of the municipal fertility over the decade (i.e. make it less negative). This result, again, is counterintuitive and is probably a consequence of the addition of the spatial error term, LAMBDA. It is also worth noting that the variation in the TFR of near neighbors, although statistically significant, does not improve the model very much (R^2 = 0.765).

Table 3. OLS (with spatially correlated errors) coefficients for TFR change[36]

	Δ TFR				
	Model 5	Model 6	Model 7	Mean	P-value
Constant	-0.297	1.313	1.227	-	0.00
Δ Child Mortality	0.007*	0.001	0.001	-15.37	0.08
Δ Percent of hh. w/ TV	-0.009	-0.003	-0.003	25.75	0.00
Δ Index of Education	-2.205	1.119	1.053	0.14	0.00
LAMBDA	0.770	0.778	0.802	-	0.00
TFR in 1991		-0.581	-0.586	3.74	0.00
Δ TFR of near neighbors		-	-0.147	-0.87	0.00
R^2	0.485	0.761	0.765		
Akaike info criterion	8794.60	4563.01	4510.05		
Br-Pagan test prob.	0.000	0.00	0.00		

* Child mortality was statistically significant in model 5 (P-value<0.001).

[35] The coefficients of determination are not as high as the ones reported by Potter et al. (2002: 752) – " 0.91 for rural zones and 0.93 for urban zones" – because they considered fewer observations in their analysis, thus they also had less variation in the relationship between dependent and independent variables.

[36] This model uses only the variables accounting for most of the variation in fertility. The other variables (percent of whites, sex ratio and urbanization rates) had very small variations over the decade to account for any significant change in the variable of interest. The critical distance used in the estimation of the LAMBDA coefficient was 100 kilometers.

The most important variables in the model are the change in the index of education and the TFR prevailing in 1991. The effect of the previous level of fertility is evident and consistent with the literature (Weeks et al. 2002). It shows that places where fertility was higher in 1991 are the same where the decline was the most remarkable. After including the lagged TFR, the coefficient of determination increased from 48 to 76 percent, and the coefficient of "Δ Index of education" became positive. According to models 6 and 7, places where education increased the most should also have had the lowest decline in fertility. This suggests that TFRs are more related with its historical trends than with changes in education. Although this explanation may sound counterintuitive at first, it is compatible with a perspective in which education is only a proximate, and not a direct, determinant of fertility (Bongaarts, 1978, 1982). Education does not directly influence fertility; rather, it influences the timing of marriage and the likelihood of using means to prevent pregnancy (Weeks et al. 2004: 84).

In sum, models 1 to 7 demonstrate that the spatial correlation of the errors play an important role in association with fertility. The effect of LAMBDA shows that there are factors over space that are correlated with fertility and that may, indeed, do a better job in predicting fertility than, for instance, the fertility of neighbors. All the models, however, violate the assumption of homoscedasticity[37]. The low probability of the Breusch-Pagan test suggests that there is still heteroskedastic in the model even after introducing the spatial error term and the TFR of near neighbors – which can be understood as a type of spatial lag term. Moreover these global models do not consider the heterogeneous specificities of spatial relationships between independent variables and fertility and fertility changes. If relationships vary significantly over space, then a local analysis would be more reliable, efficient and closer to real world patterns than a traditional global-level analysis that may be averaging away interesting associative variations. To address this hypothesis, in the next section I estimate geographically weighted regressions.

Local Relationships Between Fertility, Development and Diffusion

The GWRs follow the specifications described in Equations (7), (8) and (9). The superiority of GWR over other methodologies is demonstrated by the higher overall coefficients of determination and lower Akaike Information Criterion (AIC) of GWR (Table 4) [38]. Moreover, the ANOVA test an the test for the spatial variability of parameters (not reported) indicate that the GWR models have significant improvement over the global OLS models, and that significant non-stationary relationships between fertility and each one of the socioeconomic and neighborhood attributes exist in Brazil[39]. Appendixes 5 and 6 provide local goodness of fit statistics for the three models and point

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[37] The assumption of homoscedasticity fails when the variance of the unobservable/unmeasured factors changes across different levels of an explanatory variable of interest. The presence of heteroskedasticity does *not* bias the OLS estimators but it can affect the efficiency (i.e. errors, *t*-statistics, and *p*-values).

[38] The Moran's *I* statistic of the residuals (not reported) was lower than 0.0, suggesting therefore a lack of spatial autocorrelation, thus homoscedasticity.

[39] In 1991, the hypothesis of stationary parameters was rejected for all variables (P-value<0.001). In 2000, the coefficient of female labor force participation was non-significant, that is, stationary. In the model of fertility change, all coefficients were significant at 0.1% level, except the index of education, which was significant at 5% level.

that, indeed, there is a lot of variation in the performance of the models over space. In 1991 and 2000, the local R^2 values indicate that the models performed particularly well in the north and in the northern part of Minas Gerais. The model for changes in fertility had a good fit in most parts of the country.

Table 4. Comparison between different models

	Adj- R^2	Akaike info. Criterion
Classic OLS		
1991	0.76	(4,939.89)
2000	0.64	(5,937.06)
Change91-00	0.70	5,610.10
OLS w/ spatial error		
1991	0.81*	(5,942.43)
2000	0.74*	(7,257.76)
Change91-00	0.76*	4,891.73
GWR		
1991	0.83	(6,399.68)
2000	0.75	(7,551.84)
Change91-00	0.77	4,343.96

* Not adjusted

To examine the non-stationarity of the models I mapped the variables that had the strongest association with fertility (left) and their respective local coefficients (center) and pseudo-t values (right)[40]. From the maps in Figures 4 and 5, two observations emerge.

First, it is clear that the established linear relationships between fertility, socioeconomic factors and the fertility of neighboring municipalities vary across space and are not necessarily significant everywhere in the country. For instance, in 1991, education (Figures 4a and 5a) had a significant negative association with fertility in the northern part of Rio de Janeiro, in the center of Minas Gerais – in the area surrounding the capital – and in all the coast of Santa Catarina. In 2000, this association became non-significant in Rio de Janeiro, while the fertility of several municipalities in Goiás and in the surrounding areas of the country capital, Brasilia, started to show a strong association with the index of education. Turning to the percent of households with TV (Figures 4c and 5c), the maps indicate that this variable had the expected negative effect on fertility in Pará and in most parts of Mato Grosso and Bahia in both years. Child mortality (Figures 4d and 5d) had a significant positive effect in all the states in the northwestern part of the country, in Santa Catarina, and in several municipalities in the Northeast region.

[40] I use a significance level of 95% in the t-surfaces. That is, parameters whose t-values are within the interval [-1.96, 1.96] are considered non-significant.

Second, the fertility effect of surrounding areas (Figures 4b and 5b), the t-surface maps confirm the high statistical significance of this variable in the entire country. In 1991, this variable was not significant in most municipalities in the south and in isolated areas in the north, but in 2000, the positive association with the fertility of neighboring areas not only became stronger, but it also became more significant in the entire country. In 2000, this relationship was particularly strong in the states of São Paulo, Piauí, Ceará, Rio Grande do Norte, Paraíba, Sergipe and in a considerable part of Bahia. It is also worth pointing that, not surprisingly, the effect of neighboring fertility in the Amazon region was very small. This is probably because of natural geographic barriers imposed to communication, and because of the low demographic density prevailing in this region, which is sparsely populated.

Turning to Figure 6, the results are striking. The effect of changes in the index of education (Figure 6a) was significant only in the states of Acre, Rondônia, Maranhão, and in a few areas in Eastern Bahia, Pará, and Northern Minas Gerais and Tocantis. In all these areas, the fast increase in education was not necessarily related with a fast decline in fertility. Surprisingly, and in agreement with the global model, large changes in education were associated with smaller changes in fertility. Places where education increased the most coincide, to some extent, with places where fertility had the steepest decline. However, this apparent inverse relationship seems to be true only when the confounding effect of the previous level of fertility is not taken into account. Figure 6b shows that, indeed, the TFR prevailing in 1991 is an extremely strong and significant predictor of changes in fertility in the whole country, particularly in most non-metropolitan areas of the northeast, Rio Grande do Sul, Rio de Janeiro and Eastern Mato Grosso. In these areas, the positive[41] correlation between lagged fertility and fertility decline was the strongest.

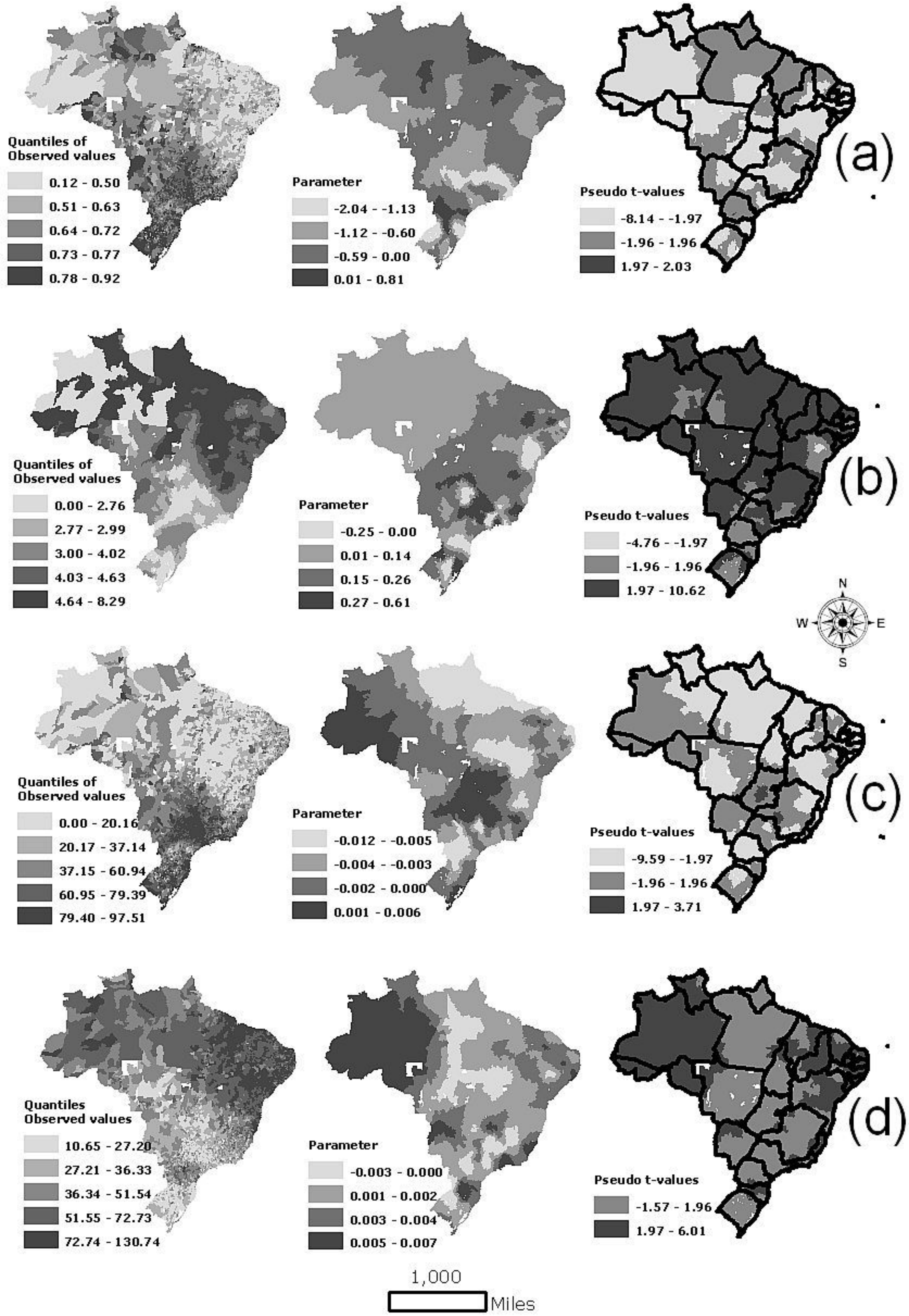
The increase in the proportion of municipalities with TV had a mixed effect. This variable was not statistically significant in Sergipe, Alagoas, Paraíba, southern Tocantis, and for most municipalities in Bahia. In other states, like Piauí, and in the coast of Paraná and Santa Catarina, the increase in the percent of households with TV had a positive and significant effect (Figure 6c), meaning that the increase in this variable was associated with small changes in fertility. Nevertheless, in most northern states, as well as in the north of Maranhão, Ceará and Rio Grande do Norte, the large increase in the percent of households with TV was positively associated in the faster decline of fertility in these regions. In the case of child mortality, the north of Minas Gerais and Goiás, Acre and the central part of Pará had positive, and significant, coefficients – i.e. the decrease in the child mortality helped to accelerate the decline of fertility. In most of the south, southeast, and mid-west regions, changes in child mortality had no significant association with changes in total fertility rates (Figure 6d right).

As a final point, it is important to remember that in all the models the observed spatial variation could be the result of local model misspecification or could, indeed, indicate intrinsically different relationships over space. In either case, GWRs are useful to

[41] A positive coefficient means that TFRs in 1991 are associated with a large, and negative, change in fertility over the decade. Remember that fertility changes are measured as TFR2000- TFR1991.

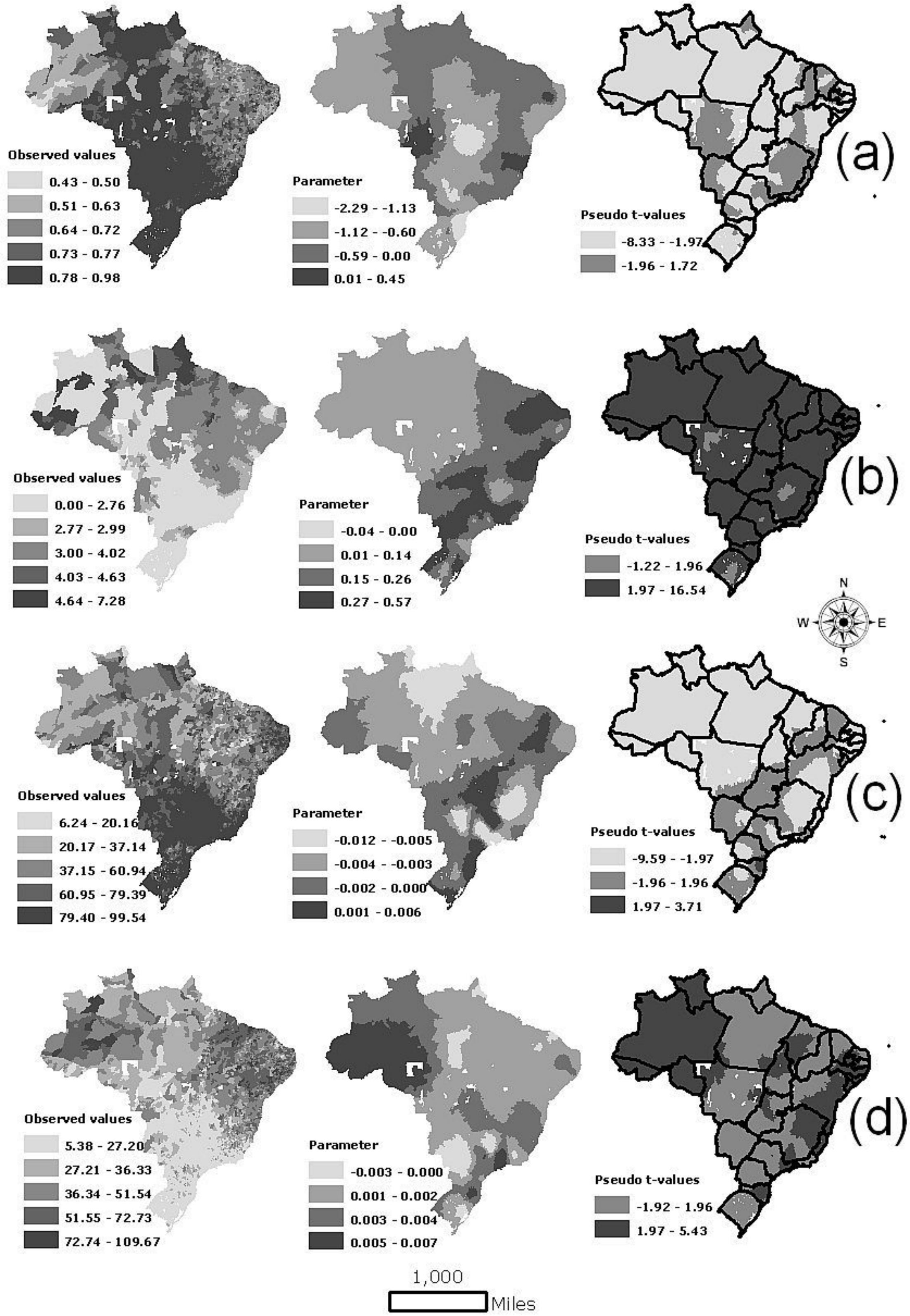
signalize that spatial variability exists and that a global specification may mask interesting relevant local relationships.

Figure 4. Observed values, spatially varying coefficients and *t*-surfaces, 1991



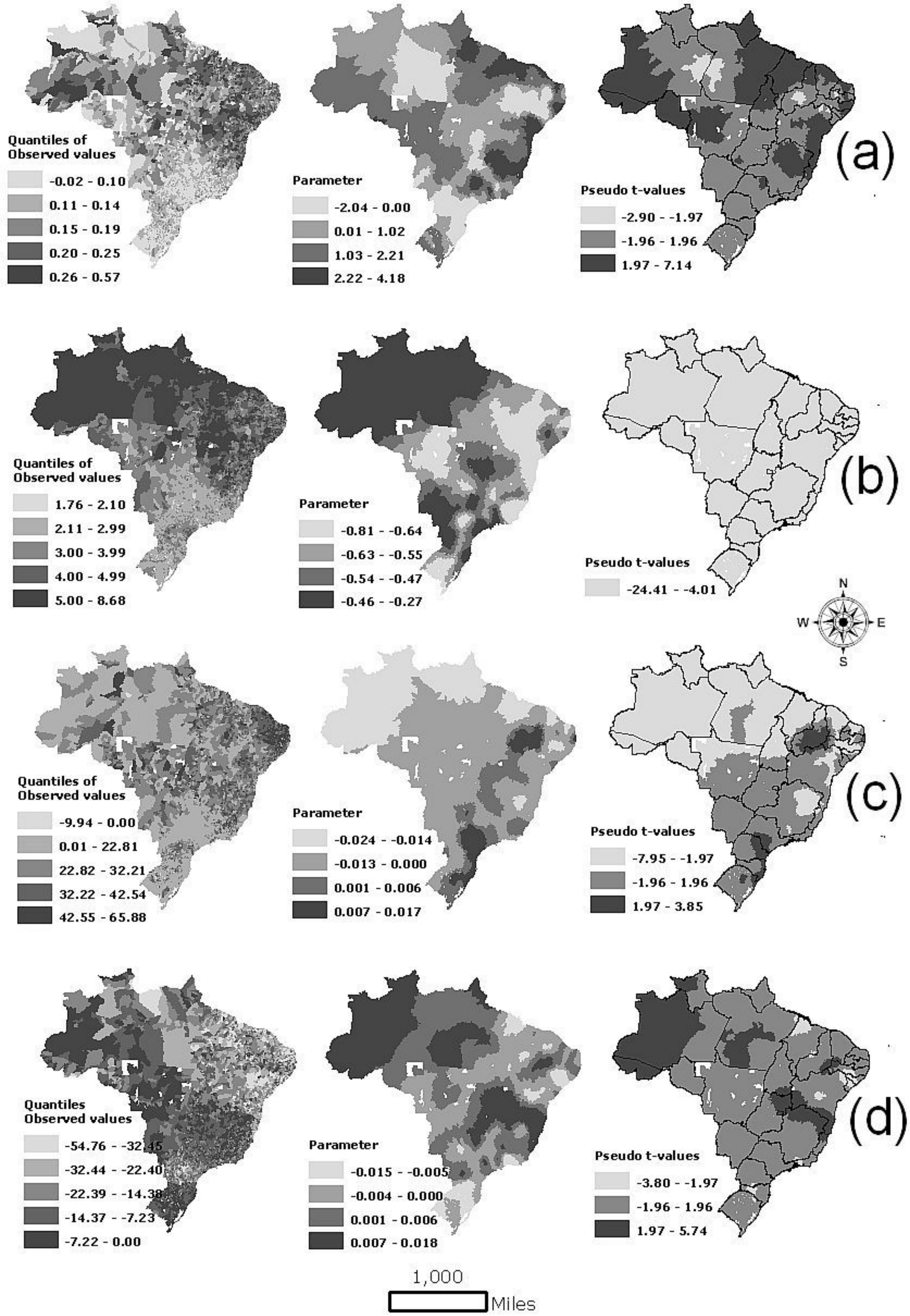
(a) Index of education; (b) TFR of near neighbors; (c) percent of households with TV; (d) Child mortality

Figure 5. Observed values, spatially varying coefficients and *t*-surfaces, 2000



(a) Index of education; (b) TFR of near neighbors; (c) percent of households with TV; (d) Child mortality

Figure 6. Observed values, spatially varying coefficients and *t*-surfaces, TFR change



(a) Δ Index of education; (b) TFR in 1991; (c) Δ percent of households with TV;
(d) Δ Child mortality

Conclusion

During the 1990s, the logistic curve describing the pace of the fertility decline in Brazil reached an inflection point of deceleration (Figure 1). While this is true in the interregional level, where the compositional differences are averaged out, in the intraregional level there is still a lot of variation in total fertility rates. When small geographic areas are aggregated into larger units of analysis, important intraregional differences are lost. As Figure 2 shows, many municipalities, especially in the north and northeast of the country, still face fertility levels much above the regional and national average, in spite of the recent and fast improvements in education, mortality and infra-structure.

The geographic aggregation fallacy is also corroborated by ecological studies trying to model the effect of socioeconomic factors on fertility. In ordinary global regressions – i.e. OLS with regional fixed effects – spatial dependence and heterogeneities are often not taken into account, leading to deceptive results and misleading inferences. In this study I show that geographically weighted regression (GWR) is the best method to investigate the association between total fertility rates and relevant socioeconomic variables because it approximates real world patterns by considering local, rather than global, relationships. Moreover, this study improves a previous investigation of fertility decline in Brazil (Potter et al. 2002) by incorporating the so called neighborhood effect of fertility in the cross-sectional models of 1991 and 2000, and by incorporating the level of fertility of the previous period in the model of fertility change. Besides reducing the omitted variable bias, the inclusion of these variables also provides an alternative, although speculative, way of testing for the presence of diffusion.

The GWR approach shows that the relationships between education, child mortality, the percent of households with television and fertility are non-stationary, neither in space nor in 1991 or 2000. All variables in the GWRs show a very distinct spatial drift. Each of these variables seem to be more important predictors of fertility in the northern and northeastern part of Brazil than in the southern and southeastern part, although the relationships are not statistically relevant in all municipalities of the country. The neighborhood effect of fertility, on the other hand, is highly significant, particularly in 2000. The fertility of near neighbors was positively correlated with municipal TFRs in areas of low (São Paulo, Santa Catarina, Rio de Janeiro) and high (Piauí, Ceará, Rio Grande do Norte) fertility. This result, I argue, provides a strong initial evidence to suggest that fertility may indeed have a diffusion mechanism dependent on distance, such as suggested by Brown (1968, 1981) and, more recently, by Weeks (2003), and Weeks et al. (2000, 2002, 2004).

In an attempt to understand why fertility declined faster in some areas of the country than in others, I also modeled the change of fertility as a function of changes in socioeconomic variables and the fertility level observed in 1991. The results of the model intriguingly show that the amount of change in the value of socioeconomic variables was more relevant to the pace of the fertility decline in areas where the variation of the former was more accentuated and where fertility was higher to start with. The endogenous level of fertility prevailing in 1991 was extremely significant to determine how much fertility declined in ten years. In particular, the inclusion of this variable in the global model with spatially correlated errors reversed the effect of changes in the index of education. This result suggests that once the lagged value of fertility is taken into account, large changes in education will not necessarily correlate with large, and fast, declines in fertility rates. This pattern was also observed in the GWR estimates. Therefore, while the cross-sectional models confirm the empirical regularity of a negative relationship between education and fertility, the predictive GWR of associative changes seem to refute this well known fact.

In a theoretical extrapolation, and as a guideline for future predictions, it is important to remember that the lagged TFR provides the position of each municipality in the logistic curve of diffusion (Brown, 1968:72). As the evolution of the Brazilian TFR follows a logistic curve in all regions, the inclusion of this variable is crucial to set the initial scene in any predictive study of fertility. In the logistic curve, places closer to the "saturated area" of low fertility are less likely to suffer further declines in the average number of births. In this sense, urban and more developed places would characterize the right tail (saturation) of the S-curve of adoption; urban developing regions and rural areas in proximity to urban centers would characterize the middle, sharply declining portion of the S-curve; and remote stagnated places would characterize the left tail of the S-curve, where fertility is still at high levels (Brown, 1981: 21-22).

In a concluding and cautionary remark I emphasize that the presence of diffusion – such as demonstrated by highly significant coefficient of the fertility of neighboring areas – is only suggestive. Without longer time series and longitudinal micro level studies nothing can be said about the direction of the diffusion. Although it seems to be a regular fact that low fertility points will always "contaminate" instead of being "contaminated," the data does not guarantee that this will always be the case. The short time period and the cross-sectional data used in this study do not allow one to say where the origin point is. It also does not prevent the anticipated endogeneity bias. Cross-sectional data cannot provide a causal link between fertility and these factors, although the evidence is certainly there. Economic improvements and distance may be a necessary condition for declining fertility rates: but not a sufficient one. Furthermore, the pace of the decline may also be affected by natural barriers not considered in this study. For instance, in the case of the sparsely populated Amazon region, terrestrial and cultural barriers imposed by isolation may play an important role in the pace of the fertility decline. In cases like this, the establishment of contact distances will only partially cover the influence of neighboring areas. The serious research should, therefore, examine fertility trends making use of longer time series, preferably longitudinal, and of to local models capable of addressing spatial dependences and heterogeneities that are relevant to shed light on our understating of fertility changes and, more broadly, of any other social phenomena that varies over space.

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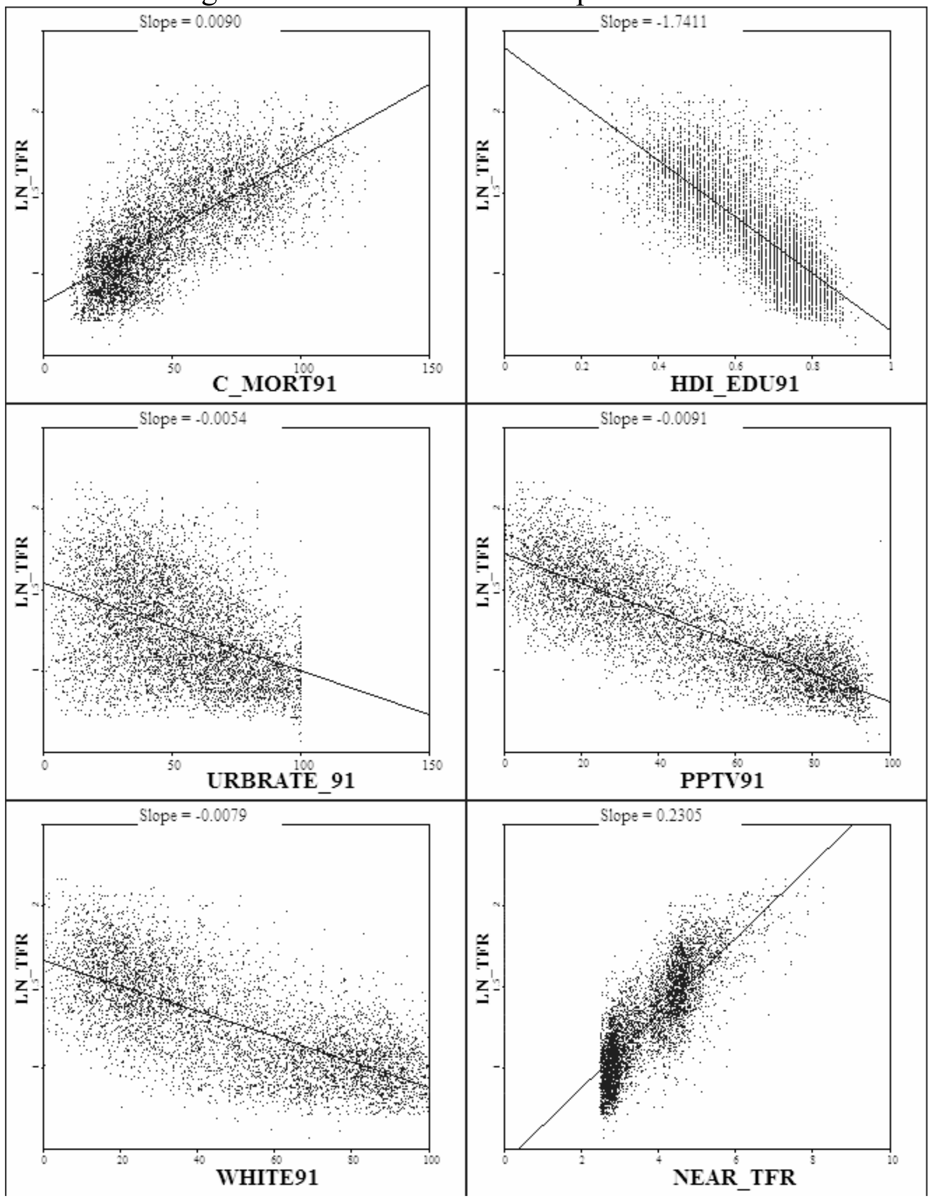
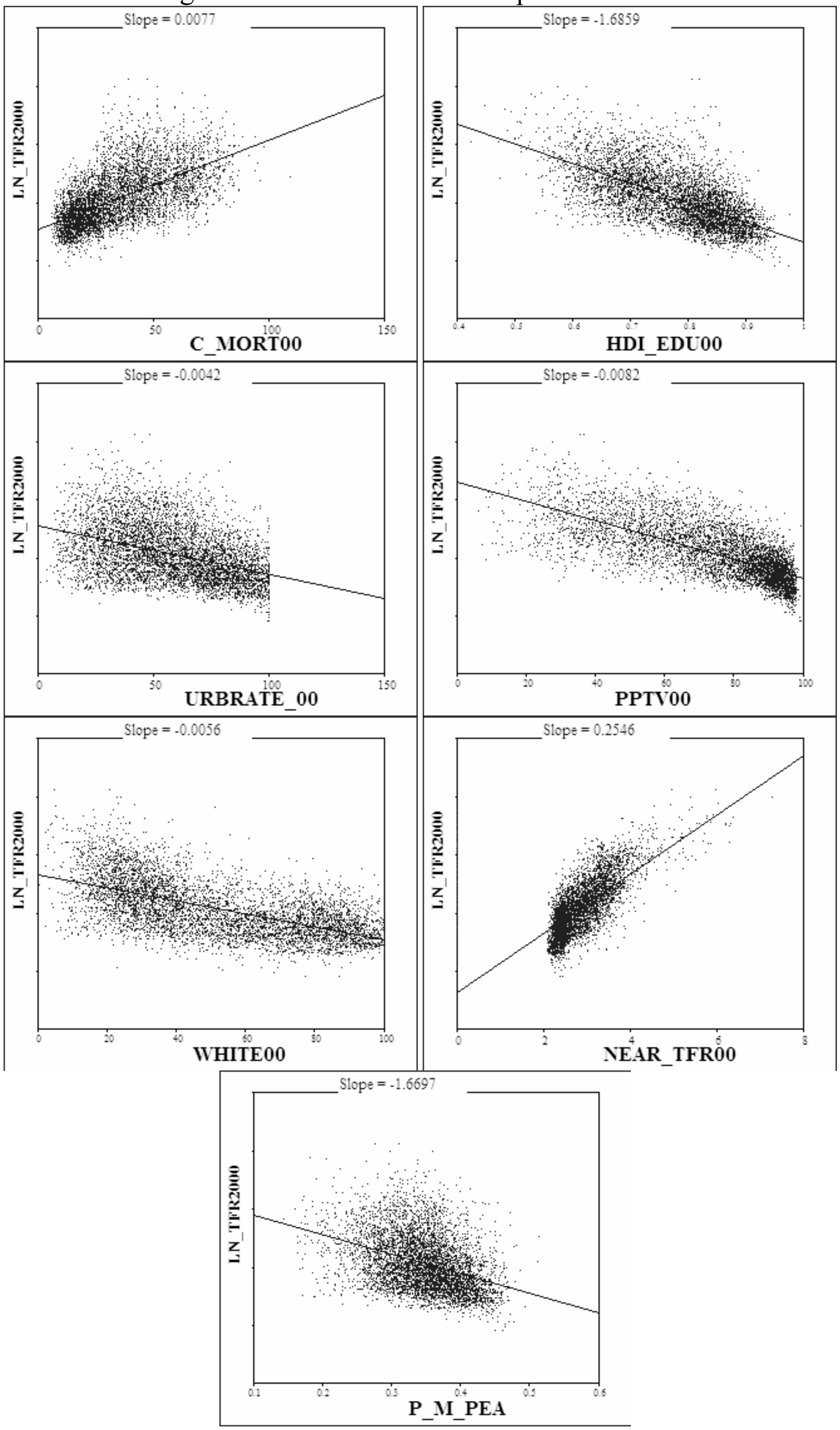
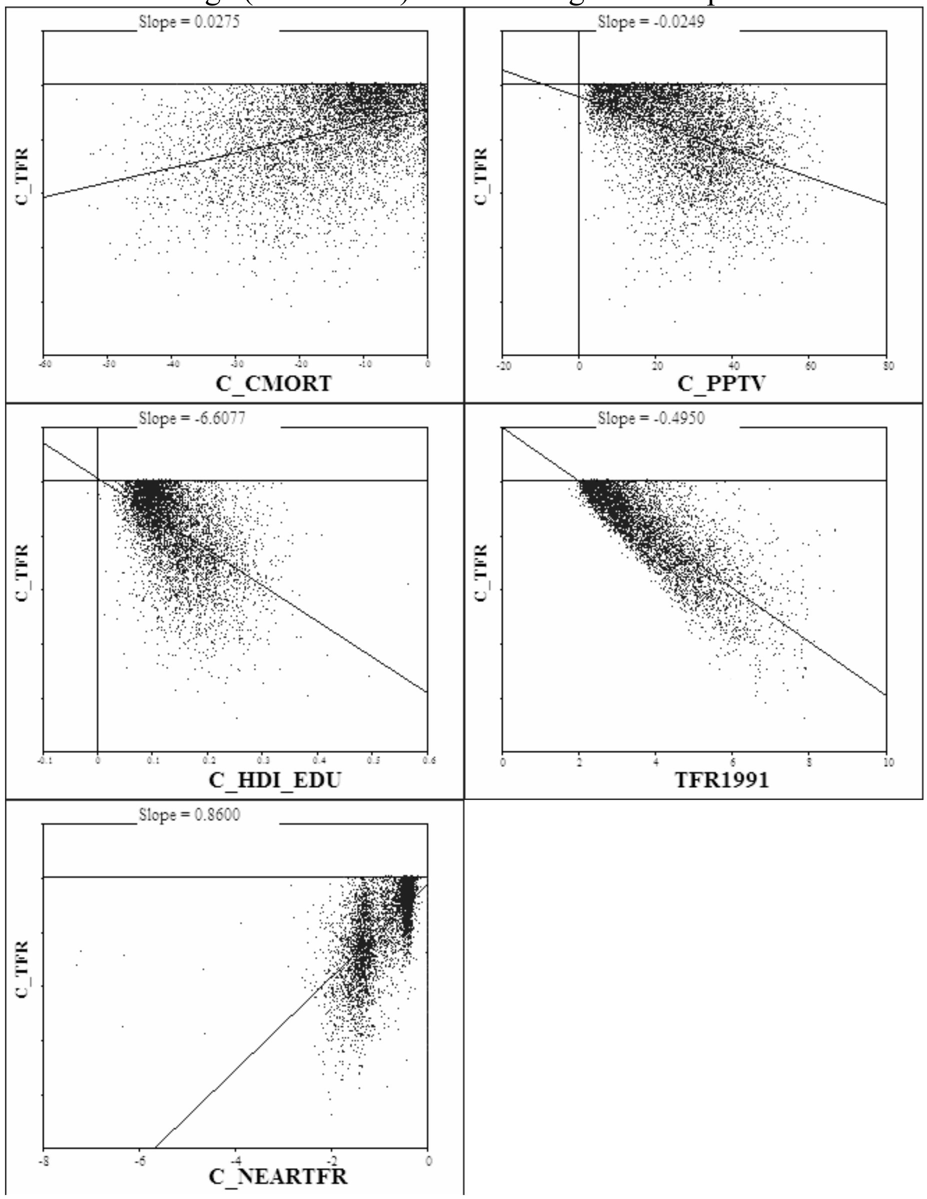
Appendix 1. Natural log of TFR in 1991 versus independent variables



Appendix 2. Natural log of TFR in 2000 versus independent variables

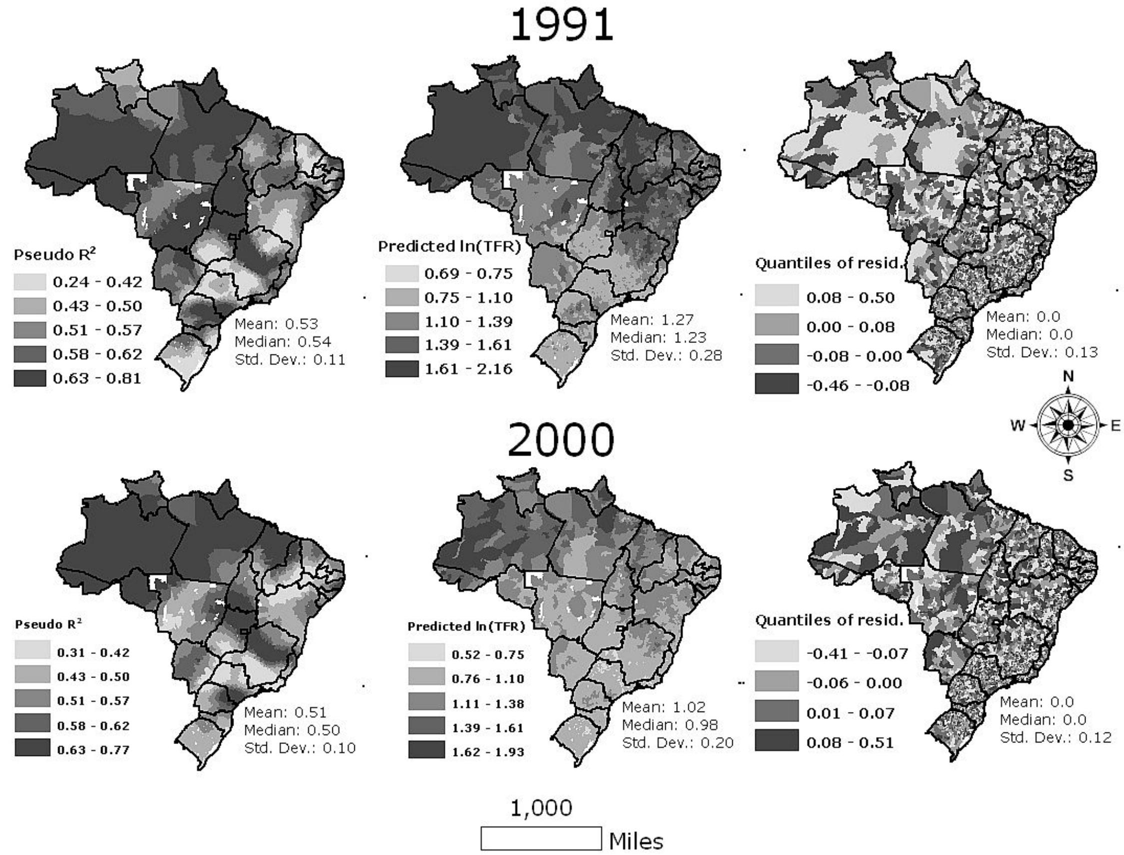


Appendix 3. TFR Change (2000- 1991) versus changes in independent variables



Appendix 4. Brazilian regions and states

Appendix 5. Goodness of fit: Pseudo R^2 (left), Predicted values (center), Distribution of the Residuals (right)



Appendix 6. Goodness of fit for fertility change model (2000- 1991): Pseudo R^2 distributions (left), Predicted values (center), Distribution of the Residuals (right)