Spatial Patterns of Fertility Transition in Indian Districts

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OVER THE PAST five decades, numerous studies have assessed levels, trends, differentials, and determinants of fertility in India. The conclusion is that fertility decline has been low to moderate except for a few pockets of more rapid transition. Until recently, the analysis of demographic transformation in India has been limited to fertility indicators at the state level. The district-level data from the censuses of 1981 and 1991 portrayed a much more complex situation in the country as fertility differentials often proved to be as substantial within states as between states. (Figure 1 displays Indian states and large cities.) Because of India's cultural, economic, and geographical diversity, the magnitude of regional variations in fertility levels is much larger than that in China, and comparison with the demographic history of Europe or of the former Soviet Union would be more appropriate.[1]

Within the context of demographic heterogeneity, this article seeks to update our knowledge on fertility levels in India and to extend our understanding of the mechanisms behind regional variations. We present the results of a new estimation procedure to reconstruct the Indian fertility transition and describe some of its spatial and statistical properties. Rather than test hypotheses on fertility–economy–society linkages through an econometric model,[2] we focus on the spatial structuring of reproductive behavior in India: fertility is examined as a *regionalized* variable, that is, a variable which is assumed to be spatially continuous.[3] As our maps suggest and the geostatistical analysis demonstrates, spatial variations of fertility in India are far from random, a fact that has potentially significant implications for our interpretation of fertility decline. Specifically, we suggest that preoccupation with the effect on fertility of factors that are poorly correlated with spatial location, such as family planning campaigns or structural transformations of the economy, may have concealed the progression of fertility change through diffusion processes at the microlevel.

FIGURE 1 Indian states and major cities

Sources for studying the Indian fertility transition

Using the age distribution of the 1961 and 1971 Indian censuses, Adlakha and Kirk (1974) concluded that the level of fertility during the early 1960s did not differ substantially from the level during the early 1950s. As they summarized their findings: “The crude birth rate in India declined by between seven and 10 per cent, from a level of about 45 in 1951–61 to about 40.5–42.0 in 1961–71” (p. 400). Extending the same data up to the 1981 census, Rele (1987) concluded that the total fertility rate remained stable at around 6 during the 1950s and into the first half of 1960s. The turning point in Indian fertility seems to have occurred around 1966, with an estimated TFR of 5.8 in 1966–71, 5.3 in 1971–76, and 4.7 in 1976–81. The estimated levels and trends of fertility for 14 major Indian states showed remarkable geographic consistency, with northern states having higher fertility than southern states in 1961–66 and, with only slight modifications, in 1976–81.

Jain and Adlakha (1982) corroborated that the fertility rate in India before 1961 was high and stable. Their analysis indicated that the crude birth rate in India fell from 41 births per thousand in 1972 to 35–37 in 1978 and that the decline was primarily caused by declining age-specific fertility rates. As in the case of two national surveys, analysis of the age distributions of the censuses of 1971 and 1981 suggested that a major fertility decline was underway during the intercensal period (Preston and Bhat 1984). A large share of this decline probably occurred in the late 1970s; the fertility reduction seems to have been slightly faster in the southern states.

Assessing the degree of heterogeneity in fertility behavior within Indian states, Guilmoto (2000) concluded that fertility decline began in the periphery along the coasts and in the extreme south, and spread progressively to encircle the region around the Ganges Valley, the heart of traditional India, where fertility has scarcely declined. The Hindi-speaking core region is characterized by high fertility, an entrenched patriarchal value system, economic underdevelopment, predominance of Brahminical influence, and exclusion of women from education. In south India, Kerala has long been recognized for its rapid fertility transition, occurring in the absence of significant economic development as conventionally measured. Female literacy is the single most frequently cited indicator in explaining this achievement.[4] A few studies have also focused on the recent fertility experience of Tamil Nadu and of south India in general.[5] Tamil Nadu is notable for having achieved replacement-level fertility without reaching Kerala’s high level of female literacy or its low level of infant mortality. Using the state-level indicators of fertility, a number of researchers have grouped Indian states into two demographic regimes: south with low fertility and north with high fertility.[6]

Very few studies permit assessment of fertility levels and trends at the district level. For the first time in the 1981 census, the Registrar General of India provided district-level estimates of fertility and mortality using indirect techniques (Registrar General of India 1988, 1989), and a few studies using these data have appeared since then.[7] For the 1991 census, the Registrar General’s indirect estimates of fertility and mortality at the district level as well as a few estimates by individual researchers are now available.[8] Bhat (1996), using the reverse-survival method, produced birth rates at the district level for the periods 1974–80 and 1984–90 and also analyzed cross-sectional variations in fertility.

More recently, using data generated by the National Family Health Survey (NFHS), Bhat and Zavier (1999) analyzed the differentials in fertility within 76 regions of the country. Among the 76 regions around 1975, none had a total fertility rate under 3 births, 12 regions were in the range of 3–4, 35 in the range of 4–5, and the remaining 29 regions were above 5. In 1987, ten regions had total fertility rates under 3, 34 were in the range of 3–4, 24 in the range of 4–5, and only eight regions were above 5. In effect, after a lapse of 12–13 years, only 30 percent of the regions had remained in their previous total fertility class. The NFHS estimates confirm the earlier finding (Bhat 1996) of substantial reductions in fertility throughout the country, not just in a few pockets.

Although the Sample Registration Survey (SRS) has been widely used to study fertility since the 1970s, it provides estimates of fertility for major states only. In recent years the SRS has published estimates for smaller states and union territories but does not provide information on fertility at the district level. Surveys conducted in a number of states (Mysore Population Study, for Karnataka; Gandhigram Institute Survey, for Tamil Nadu; Kerala Fertility Survey, for Kerala, to name a few) focus on fertility and its determinants at the state level. Against this background, this article aims to provide a new set of fertility estimates at the district level starting from the 1950s. We use a new database that integrates all district-level age data drawn from the 1961, 1971, 1981, and 1991 censuses. We devise a new index based on child–woman ratios computed from census age distributions.[9]

From the child–woman ratio to the child–woman index

Estimates derived from child–woman ratios (CWRs)[10] can be used to reconstitute fertility trends at the district level over a 40-year period. The combination of two CWRs calculated by using different numerators and denominators in the ratio enables us to estimate fertility levels for each five-year interval. Specifically, we calculated CWRs as children aged 0–4 divided by women aged 15–49 and as children aged 5–9 divided by women aged 20–54. For example, 1961 CWR values yield estimates for 1951–55 (using the 5–9-year age group as numerator) and for 1956–60 (using the 0–4-year age group). Our 1961–91 database thus provides a set of district-level fertility measurements for eight five-year intervals from 1951–56 to 1986–91.

Compared with other fertility indexes, the child–woman ratio has several limitations. The main shortcoming is that this ratio is based on surviving children in different age groups and not on the number of live births. The following simplified formula highlights this flaw:

$$\text{CWR} = \text{children/women} = \\ (\text{births x child survival}) \,/\, (\text{women x adult survival}).$$

Mortality differentials between regions or census periods may cause variations in CWRs and make comparisons between CWRs potentially misleading. Raw values of the CWR reflect fertility levels as well as child mortality levels. Furthermore, because India was characterized by rapid mortality decline during the period in question, inter-temporal variations in CWRs imperfectly reflect fertility changes over time. Correcting for the mortality factor is therefore a first requirement in improving the index.

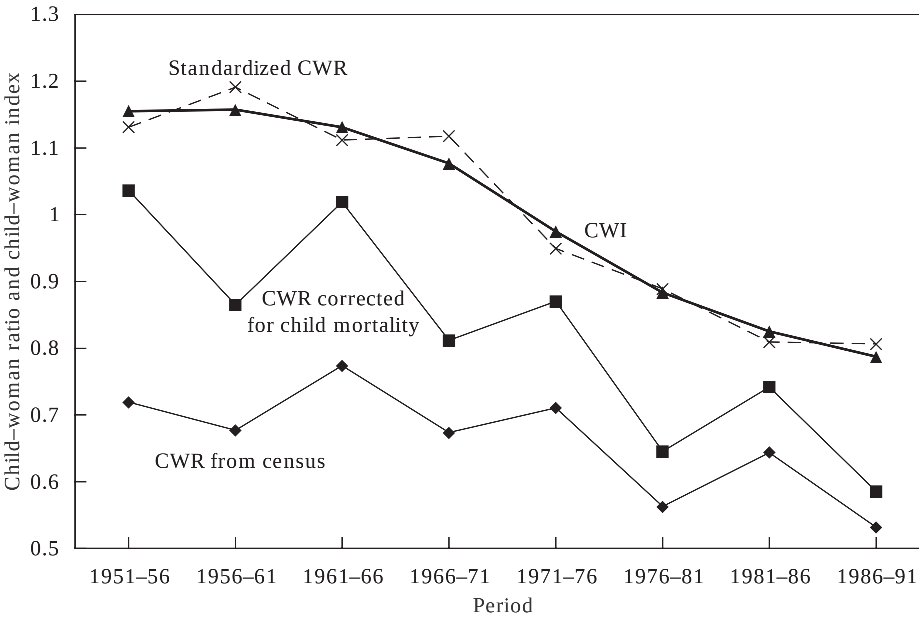
A second limitation relates to the simultaneous use of two different CWRs that are not directly comparable because they are based on different age groups. As noted above, we use both the 0–4 and the 5–9-year age groups to reconstruct fertility during the two quinquennia preceding the census year: the two CWRs require adjustment to be comparable.

Apart from the effects of child and adult mortality just noted, other limitations to the use of the CWR are related to the changing shape of the age distributions of women 15–54; gains and losses through net in- or out-migration; and the accuracy of age enumeration and age reporting. No fully adequate correction is feasible for the distortions these factors cause in the CWRs as an index of fertility. It is worth stressing, however, that our attempt is not to estimate fertility values per se, but to arrive at a comparative index of fertility trends over time and of differentials by region. Hence, we have not attempted a correction for mortality variations among the adult female population, nor have we tried to take into account migration. We consider these factors minor in explaining CWR differentials compared to the effect of the fertility component as reflected in the census data for children aged 0–9. We have also used the raw total of the adult female population aged 15–49 and 20–54 as a denominator for calculating CWRs instead of weighting age groups by their respective share according to an estimated period fertility schedule.[11] For lack of reliable and detailed estimates, we have also ignored the possible impact of changes in the completeness of the census and in the accuracy of age reporting. In view of the poorer quality of registration and age reporting in the earlier censuses, such changes may be responsible for the erratic age distributions observed in some districts. The standardization procedure explained below, which yields a measure we call the child–woman index or CWI, seeks to minimize the effect of these problems in the underlying statistics.[12]

Details of the computation of the new CWI are given in the Appendix. The index provides a comparative fertility indicator at the district level for the eight five-year periods starting with 1951–55 and ending with 1986–90. As a feature of the standardization, we equate the average value of the CWI over 1961–91 to one.

To illustrate the effect of our correction and standardization procedures, Figure 2 presents the all-India values derived from child–woman ratios, starting with the original CWR values computed from the raw census age distributions. Once corrected for mortality, the ratio displays more pronounced

FIGURE 2 Child–woman ratio and child–woman index, all-India, 1951–91



NOTE: CWRs are computed from census data, using successively children aged 5–9 and children aged 0–4. For description of the correction and standardization procedures, see the Appendix.

variations because the impact of declining mortality over four decades is removed. However, the serrated profile of these lower two curves shows that the CWR based on children aged 5–9 and women aged 20–54 is not directly comparable to the CWR based on children aged 0–4 and women aged 15–49. In fact, the former ratio (used for the 1951–56, 1961–66, 1971–76, and 1981–86 quinquennia) seems to overestimate fertility when compared to the latter ratio (used for the other quinquennia). After standardization and limited smoothing (see Appendix), the final child–woman index provides a reliable indicator of fertility variations across periods and districts.

A statistical description of the results (see Table 1) shows that while average fertility levels decreased after 1961, the variability of fertility indi-

TABLE 1 District averages of the child–woman index, India, 1951–91

	1951–1956	1956–1961	1961–1966	1966–1971	1971–1976	1976–1981	1981–1986	1986–1991
District average	1.155	1.157	1.131	1.076	0.974	0.883	0.825	0.787
Standard deviation	0.144	0.137	0.147	0.149	0.136	0.140	0.151	0.166
Coefficient of variation (percent)	12.5	11.9	13.1	13.8	14.0	16.0	18.4	21.2
Number of districts used in the computation	316	316	338	338	331	331	328	328

cators in India almost doubled during the same period. Demographic change in India is now a major differentiating factor among regions that shared a common profile during the colonial period.

Mapping fertility transition from 1951 to 1991

The next step is to plot the district values on a series of maps covering 40 years (1951 to 1991) of demographic transition in India. CWI values are first plotted on the map, using the geographical coordinates of district headquarters. The local fertility values are then converted to a surface map using kriging, a standard geostatistical procedure, to interpolate fertility values on the entire map of India.[13] Kriging is the optimal method of spatial interpolation, and it generates the most accurate estimates of surface values among available methods of spatial smoothing (see Appendix for details on our kriging procedure). The outcome consists of a "grid" made of small square cells (20 km by 20 km). After kriging, local grid values are contoured using seven value classes. The final result is a set of eight five-year maps depicting fertility transition from 1951 to 1991 (see Figure 3). Because the CWI is corrected and standardized for mortality, comparisons across regions and across five-year periods are possible. Although regional biases—resulting from such factors as serious age misstatement or differential underenumeration of children—may persist, especially for the 1961 and 1971 census data, the mapping enables us to follow regional and all-India trends and to examine 40 years of changes in fertility behavior.

The first two maps in Figure 3, for the 1951–61 period, show the limited variation in pretransitional fertility within India. The northeast, where the data quality is admittedly poor, exhibits the highest fertility levels. Several pockets of moderate fertility are visible both in south India (south Kerala and Tamil Nadu) and in mountainous districts in the western Himalayas. As further maps will show, these areas remain characterized by below-average fertility. An area of moderate fertility comprises several adjacent rural districts in central India across Madhya Pradesh and Maharashtra. This feature disappears in later maps. Although the possible effect of region-specific age misstatement cannot be ruled out, more information is required on pretransitional fertility regimes in India to elucidate this feature.[14]

Fertility increased across India after 1956 except in the moderate fertility areas of south India and the mountainous districts. The rise is especially discernible in western India and in the northern part of the subcontinent until the 1960s. (This pretransitional rise in fertility is highlighted in Dyson and Murphy 1985.)

In the 1960s, fertility decline began in several areas. This reduction is most pronounced in the southern tip of India.[15] The drop in fertility is also visible in Tamil Nadu and Kerala, as well as in south Karnataka and Andhra

FIGURE 3 Child–woman index, 1951–91

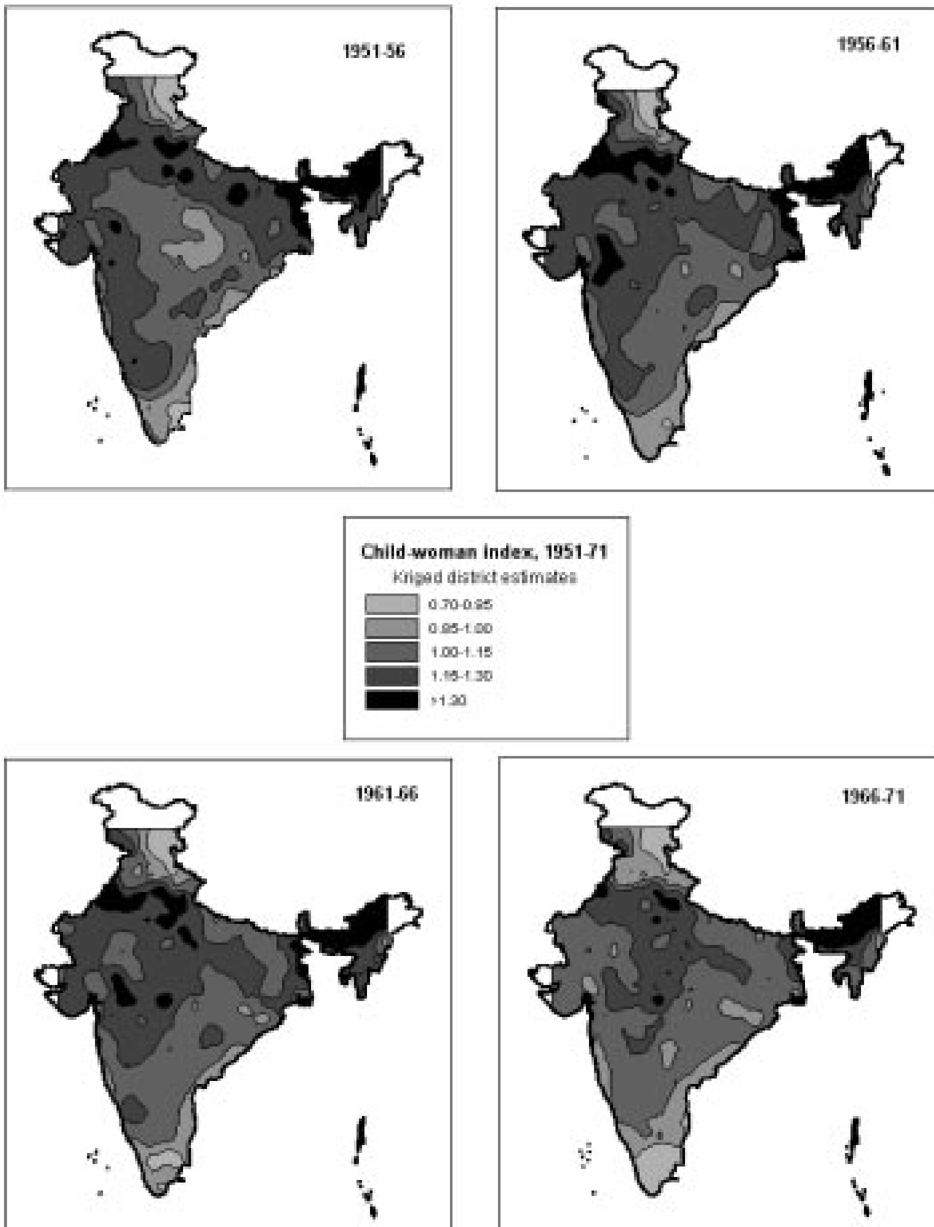
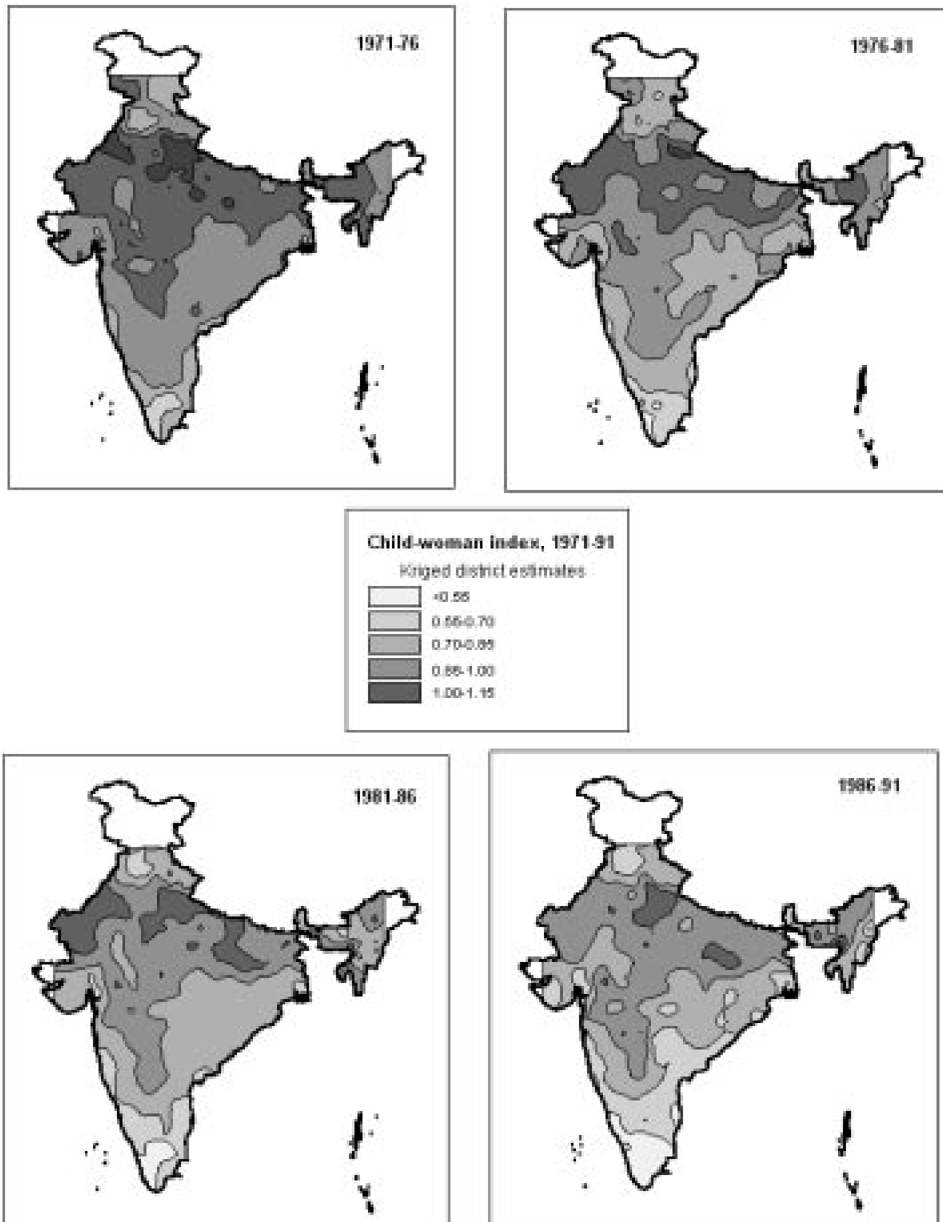


FIGURE 3 (continued)



NOTE: Blank areas refer to areas for which kriging is not possible (see Appendix).

Pradesh. Interestingly, coastal areas both in the west (from Mumbai in Maharashtra to Goa) and in the east (almost the whole of coastal Andhra Pradesh) are affected.[16] The geographical logic of this decline is pronounced as all the affected regions are contiguous. Other regions in India exhibiting a downward trend in the fertility index were the high-altitude areas in Himachal Pradesh and Jammu-Kashmir as well as the north of Punjab. Ironically, Punjab, whose wheat-growing plains had reaped the early benefits of the Green Revolution during the 1960s, was cited during the same period as the high-fertility area par excellence in an influential debate on the rationale for fertility behavior in developing countries.[17] Adjacent areas in the state of Haryana and western Uttar Pradesh, where agriculture also made great progress during the same period, show no trace of fertility reduction. The Punjab–Haryana border, which more or less demarcates Sikh-dominated Punjab from Hindu-dominated areas (Haryana and Uttar Pradesh), still separates areas of low and high fertility, as is evident on our maps for the late 1980s.

The first four maps in Figure 3, covering the period 1951–71, show that the high-fertility areas of northern India gradually formed a single block centered near the border between the three states of Rajasthan, Uttar Pradesh, and Madhya Pradesh. Another core area characterized by high fertility comprises the Brahmaputra Valley in the northeast state of Assam, the northern portion of West Bengal, and some smaller states in the northeast such as Meghalaya and Arunachal Pradesh. In other states of the northeast (Nagaland, Manipur, and Mizoram), where many regional tribes have been Christianized, literacy tends to be higher and fertility is more moderate.

The maps in Figure 3 that pertain to the 1970s, a period characterized by aggressive family planning campaigns in India, show the gradual spread of fertility decline across most regions. The fall is most visible in southern India, below a line that could be drawn from Gujarat in the west to Calcutta in the east. Although the pioneering districts of Kerala and Tamil Nadu are still far ahead, fertility decline has been rapid everywhere in south and central India. New pockets of pronounced fertility reduction have become visible in Gujarat and in southern districts of West Bengal. In the latter region, fertility has already reached a low value in and around the city of Kolkata (formerly Calcutta) by the 1970s, but this downward trend also manifests itself in the entire southern part of the state.

The coastal pattern of fertility change is still evident, especially as interior districts in the Deccan Plateau have experienced a less rapid pace of demographic change. The eastern tip of Maharashtra (Vidharba) and a few districts in Uttar Pradesh around the cities of Lucknow and Kanpur represent exceptions to early fertility decline in interior India. In the northwest, the fertility decline becomes pronounced in all Punjab districts and in the union territory of Chandigarh. Fertility decline has still not spread as might have been expected to adjacent rural areas in Haryana and western Uttar Pradesh. On the contrary, the decline seems to have expanded from Himachal Pradesh toward the northwest of Uttar Pradesh (Kumaon), which comprises several mountainous districts at the foothills of the Himalayas.

The picture becomes more complex during the 1980s. Although fertility decline is occurring in almost every region of India, persistent differentials between subregions give our maps a patchwork appearance. A major feature of this period is the significant contraction of the high-fertility zone in India that formerly covered most of Bihar, Madhya Pradesh, Rajasthan, and Uttar Pradesh. Fertility has decreased considerably in central Uttar Pradesh, while less concentrated decline was underway in Rajasthan and Bihar. In the northeast, the demarcation between the western states (Assam, Meghalaya, and Arunachal Pradesh) and the eastern states (Manipur, Mizoram, Nagaland, and Tripura) became more acute, as the latter have recorded rapid fertility decline. By the late 1980s, fertility in Manipur and Nagaland was as low as in south Indian states.

In the south, the fall in fertility rates in the 1980s accelerated nearly everywhere. In many districts of Kerala and Tamil Nadu, values of the child–woman index reached a value less than half of those estimated for north India. Districts with the lowest values of the index were still highly concentrated in two pockets, in west Tamil Nadu (Coimbatore region) and in south Kerala. Whereas fertility decline in north India has profoundly redrawn the map of fertility differentials, relative variations between subregions in the south have been more or less preserved. Only the central region of the Deccan Plateau (central Maharashtra, north Karnataka, and sections of western Andhra Pradesh) seems to have remained a partial exception to fertility decline—not unlike the western districts of Uttar Pradesh, where any diffusion of the rapid decline in the Punjab and Himachal Pradesh seems to have remained minimal.

Three fertility profiles

Exploring the individual cases of hundreds of districts that may have little in common in terms of social, cultural, or economic characteristics would be a tedious exercise. Many local fertility trends may be explained by unique sets of historical characteristics, bearing little resemblance to conditions in neighboring areas. At the same time, paying attention only to broad regional aggregates, such as state average values, would obscure fertility trends that stand out on our contour maps. We have, therefore, opted for a statistical reexamination of our district-level estimates in order to identify major "fertility profiles" as a means to describe 40 years of demographic change in India. Because correction and standardization procedures for the child–woman index yield a consistent time series for several hundred Indian districts, we have performed a cluster analysis on this database, using districts as observation units and the various five-year fertility estimates as variables. The cluster analysis is a technique aimed at providing the best partition of our district units. After repeated trials, we opted for a three-way partition of our district sample as the most convenient for analysis and presentation.[18]

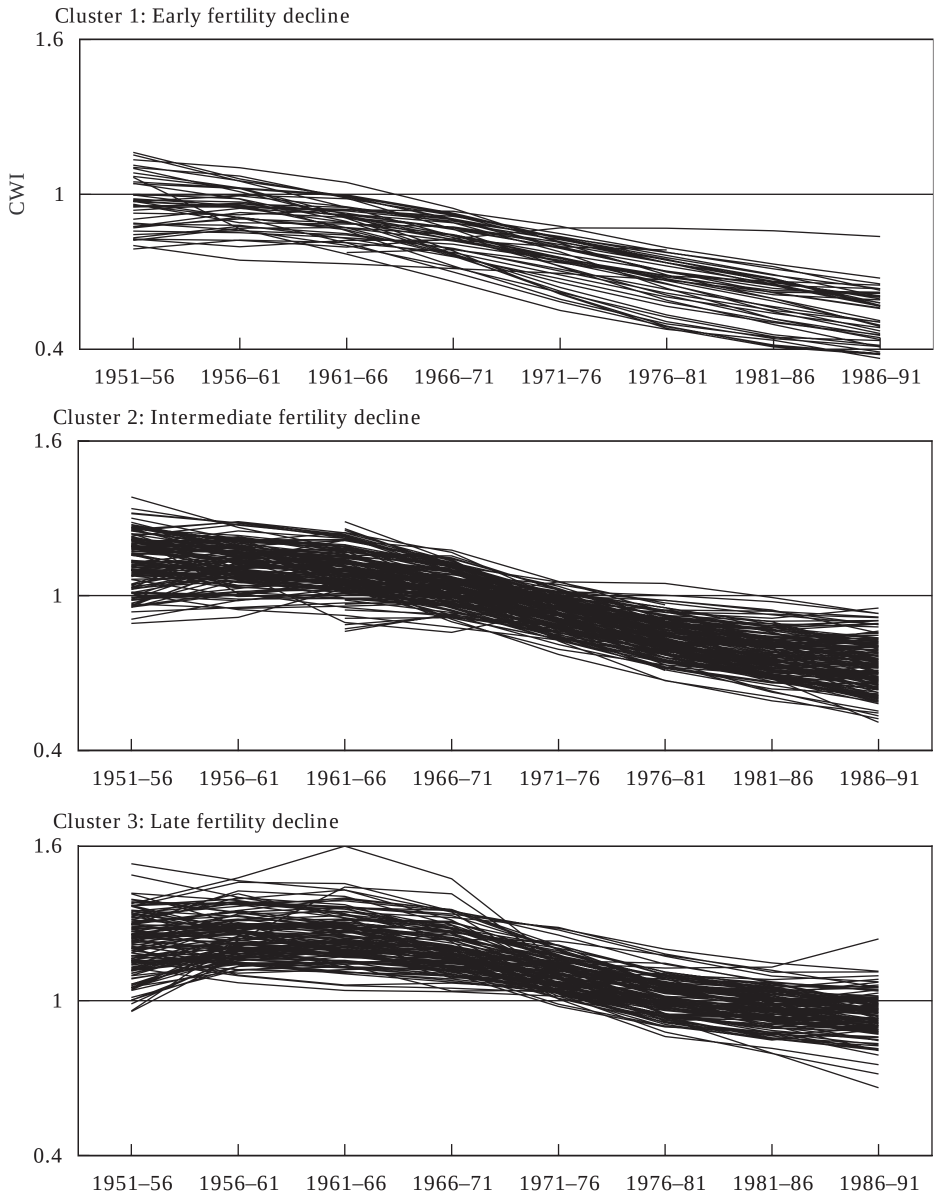
The clusters that divide Indian districts into three fertility groups include respectively 44, 159, and 135 districts. While fertility characteristics in the three clusters share some structural features such as the downward trend over the last 30 years, they differ widely in three highly visible characteristics: maximal observed fertility level, date of onset of sustained fertility decline, and fertility level in the most recent 1986–91 period. Figure 4 brings together the values of the child–woman index for all districts in each category. In spite of the groupings, a significant degree of heterogeneity remains within each fertility cluster. The smoothing procedure has not removed all traces of local differences. A few districts still display extreme levels of fertility or abrupt changes. Reasons for such fertility profiles are many,[19] but these exceptional districts represent less than 5 percent of the sample.

Figure 5 provides a summary of our cluster analysis, with average values for each fertility profile and five-year period, while the clusters are mapped in Figure 6. Because some districts were excluded from the analysis for lack of consistent time series, the map in Figure 6 does not follow the customary administrative boundaries.

Using the summary offered by the average values of the clusters (shown in Figure 5), we can delineate the distinctive features of each profile using the highest recorded fertility as the most significant marker. The main traits of this demographic turning point consist of its date of occurrence and level. The first cluster is characterized by a low level of highest fertility, which (as is also true for most districts in this cluster) falls below the 1951–91 Indian fertility average. From 1956–61 on, the average of CWI values has always been below one. The first cluster is also characterized by its early attainment of maximum fertility (before 1956), and hence by early fertility decline (1951–56). In this cluster, fertility seems to have started declining from the first decade of observation. Indeed, it has not been possible to ascertain the period of the onset of fertility decline in these districts because the highest level of recorded fertility might have occurred before the 1950s. The overall picture is one of early fall coupled with low or moderate fertility.

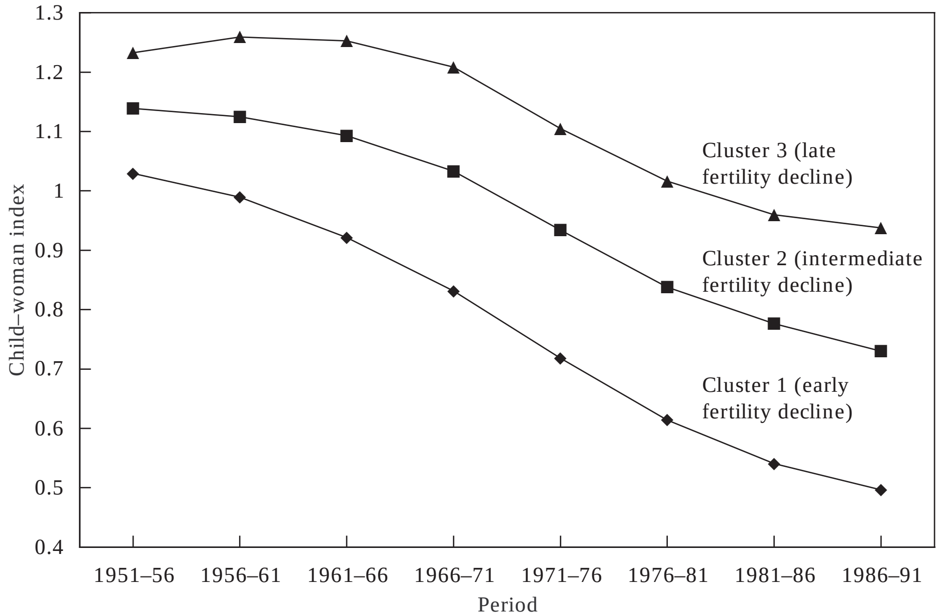
This first cluster includes a compact area covering most of Tamil Nadu and Kerala, as well as contiguous areas in coastal Andhra Pradesh and Karnataka. It also comprises several coastal areas in the west, covering Goa as well as patches in coastal Maharashtra. The only distinct region of early fertility decline to emerge in interior India is located in the northwest across Punjab, Jammu and Kashmir, Himachal Pradesh, and Uttar Pradesh. As ex-

FIGURE 4 Child–woman index, 1951–91 (districts classified by fertility profile)



pected, the first cluster includes all the forerunners of fertility decline that were identified on the previous set of fertility maps. Interestingly, this "pioneer cluster" includes few isolated areas other than Kolkata and Sambalpur district in Orissa.

FIGURE 5 Average child–woman index, all-India, 1951–91 (three fertility profiles)

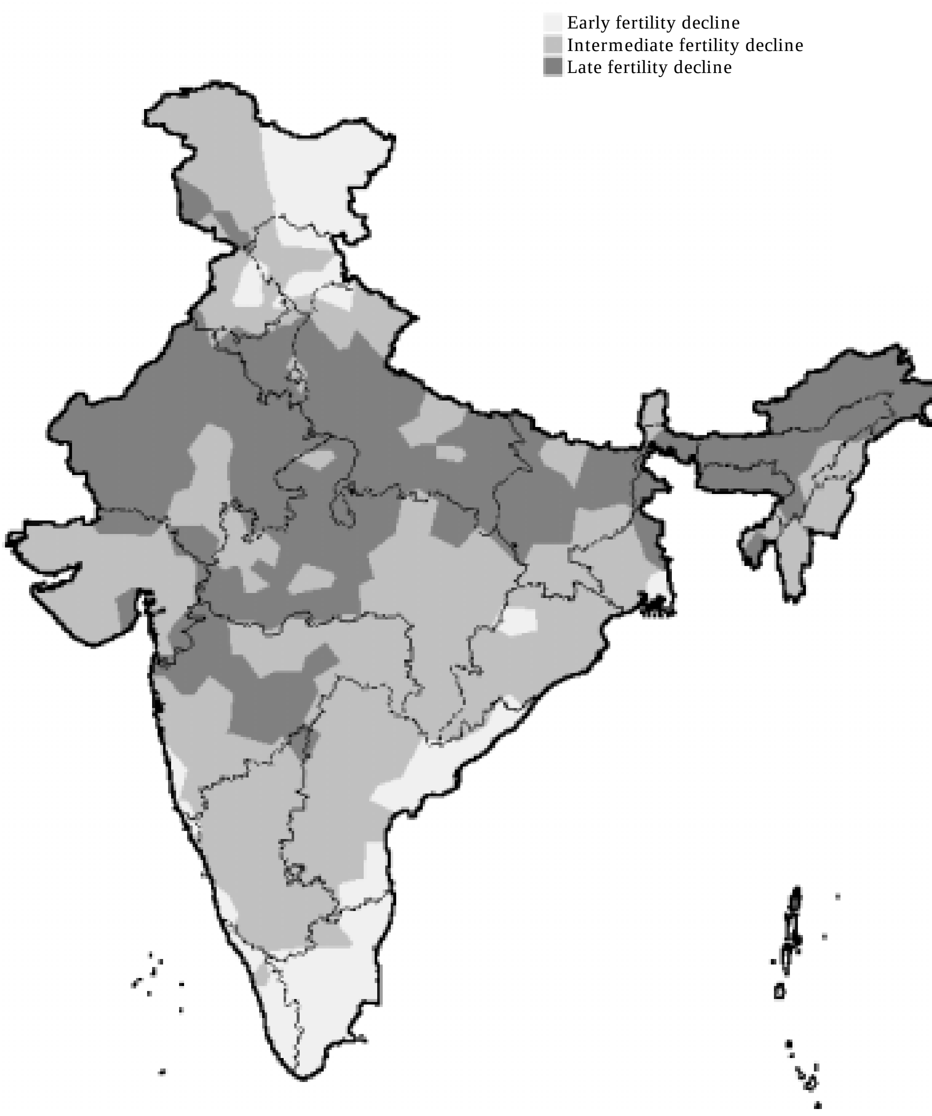


The second cluster brings together districts whose fertility profile runs almost parallel to that of the first cluster of early decliners. The major difference lies in the level of highest fertility as estimated from 1961 census data. The gap in terms of fertility levels between the two clusters is substantial and has persisted over the years, as cluster averages show. This gap corresponds roughly to a period of 10 to 15 years. The spatial distribution of these areas is clearly demarcated from that of the first cluster, with very few overlapping segments such as those in Punjab or Himachal Pradesh. These districts occupy a middle position, very close to the average Indian fertility profile.

The third cluster comprises the late decliners. It forms a large contiguous block, comprising the greater part of Bihar, Madhya Pradesh, Rajasthan, Uttar Pradesh, Haryana, and the northern tip of West Bengal, and the Brahmaputra valley including most of Assam, Meghalaya, and Arunachal Pradesh. It also includes pockets in Maharashtra and Karnataka. The third cluster is clearly separate from the first, with no common borders. Because this map involves no geographic smoothing, the fact that the resulting spatial patterning is so pronounced confirms that this striking feature of Indian fertility patterns is not a geostatistical artifact.[20]

The initial rise in fertility, which was conspicuous until the 1960s, may be another distinctive feature of so-called late decliners: pretransitional fertility during the 1950s was characterized by a significant upward move-

FIGURE 6 Three profiles of fertility transition (results from cluster analysis) by district



ment, with an increase of more than 20 percent in some districts. When fertility reached its plateau at a very high level in this cluster, it was already declining in the rest of the country. The rapid decline during the 1970s may have been partly fueled by the new population policy during the Emergency; however, fertility reduction in the 1980s seems to have decelerated substantially. Consequently, fertility levels in 1986–91 were much higher than elsewhere in India, and the gaps between fertility in the late-declining districts and fertility in other districts has consistently widened over time.

Fertility decline is a transformation affecting the social and economic structures of society down to the household level. The first phase of fertility transition is characterized by strong differentiation as some sections of the population opt progressively for new patterns of reproductive behavior, while the fertility regime remains stable in the rest of the society. In India, rising marital fertility during the 1950s and the early 1960s has undoubtedly affected a significant proportion of the districts and introduced an additional differentiating factor. Fertility in the 1970s and in the 1980s decreased, seemingly in a process of spatial (or horizontal) diffusion across all districts. The results from our cluster analysis show that the tempo of decline was faster among early decliners.

This suggests that fertility decline did not affect social structure uniformly and that vertical diffusion across local social groups was more pronounced among early decliners. In south India, data from the Sample Registration System and from the NFHS point to the rapid diffusion of fertility reduction within society in 1970–90. For instance, SRS estimates for 1971 and 1990 show that the rural–urban gap in fertility rates was reduced substantially in Tamil Nadu and disappeared in Kerala, while it actually increased in India during the same period.[21] Similarly, NFHS data and census estimates indicate that fertility decline among illiterates has been more rapid in Kerala, Punjab, and Tamil Nadu than elsewhere in India.[22] This narrowing gap between rural and urban areas and between illiterate and educated women accounts for the acceleration of fertility decline observed among early decliners.

Vertical diffusion has been less conspicuous among late decliners, and the variations across social groups increased significantly during the 1970s and the 1980s. Moreover, the spatial impact of rapidly declining fertility in Punjab and north Uttar Pradesh (Uttaranchal) on adjacent districts in Haryana or west Uttar Pradesh appears extremely limited.[23] This situation may result from the strong resistance of local institutions to the effect of social and economic changes witnessed locally and in nearby areas. They seem to be “locked-in” to a specific social and cultural configuration characterized by deeply ingrained patriarchal values that check social development.[24]

Fertility in India and spatial autocorrelation

We now address an issue common to all map-based studies of social change. Our description of the geographical features of the spread of fertility decline in India has been on a stylized level, based on the visual impression derived from our cartographic rendering. Geostatistical tools permit quantitative assessment of these spatial traits. Surprisingly, such tools have seldom been employed by demographers and other social scientists to verify their findings based on impressionistic interpretation.[25] We now present the results of a simple analysis of spatial structure using our database. Instead of using smoothed data as in our first series of maps and in the cluster analysis, we revert to the original child–woman ratios. Thus, our analysis uses the entire district sample for 1961–91, even when some district units are not present in all Indian censuses because of the recurrent process of administrative redistricting.

The index we calculated from these data is Moran's *I*. It measures spatial autocorrelation, a concept closely related to that of autocorrelation used for time-series analysis (see Appendix for detail). Spatial correlation analysis aims at capturing the effect of distance on another variable of interest. In our case, we assess the covariance between district fertility levels measured by child–woman ratios and the geographic distances that separate districts from one another. Our hypothesis is that districts that are geographically closer to one another will display the most similar fertility values.

The result of our analysis is shown in Figure 7, which plots the degree of spatial autocorrelation (Moran's *I* coefficient) on the vertical axis against discrete categories of distance measured in kilometers on the horizontal axis. A value of 1 for the coefficient would indicate perfect positive correlation, 0 no correlation, and –1 perfect negative correlation.

In calculating the coefficients, we used the location of district headquarters for computing distances between districts. Coefficients pertaining to distances greater than 600 km are not shown in the figure as spatial correlation beyond this limit is invariably very low. We confine ourselves to a few comments in interpreting our calculations:

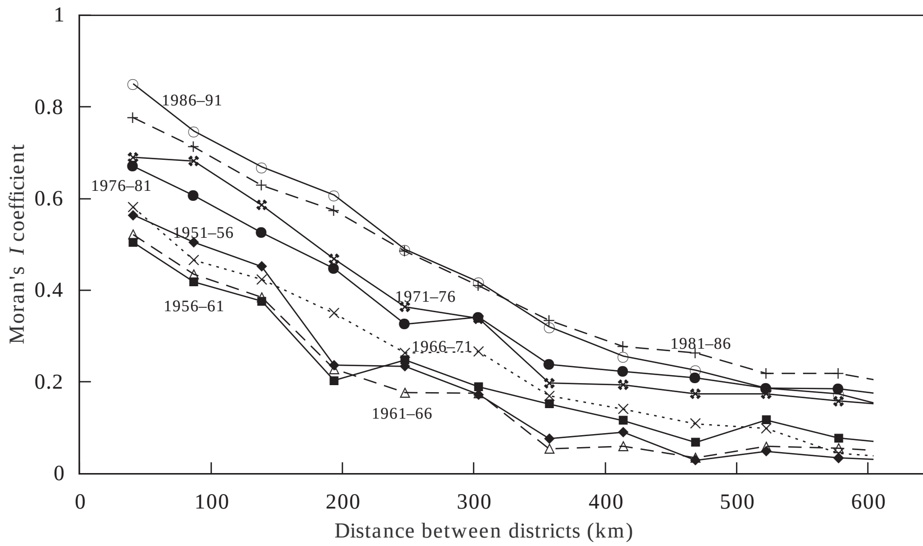
—As expected, spatial correlation decreases regularly as distance between districts increases.

—Spatial correlation coefficients are very high for short distances (above 0.5 for distances between districts of less than 50 km).

—Spatial correlation coefficients tend to increase regularly over the five-year periods shown.

These results help to confirm some of our previous descriptions of spatial patterns of Indian fertility. Spatial structuring has a strong influence on fertility levels and trends at the district level, and this "neighborhood effect" is still felt at distances greater than 300 km. Districts separated by greater distances display very low spatial correlation. On balance, the major finding of this analysis is that observed spatial correlation among fertility indexes increases regularly over the years. It moved from moderate values in the 1950s to very high values during the 1991 census. The coefficients attain their highest values during the latest reference period (1986–91).

FIGURE 7 Moran's *I* coefficient for district fertility, 1951–91 (computed on child–woman ratios)



The interpretation of this specific feature is crucial to our argument. If the increase in spatial autocorrelation coefficients is not spurious, then fertility decline has intensified the spatial structuring of fertility behavior in India. One might argue that this increase is due in part to factors such as improvements in the quality of the data. However, it is also reasonable to assume that age misstatement affects the quality of fertility estimates more than it affects the spatial distribution of errors since adjacent districts may be similarly affected by measurement errors. As a result, we can safely assert that the spatial features of fertility levels in Indian districts have become increasingly relevant as fertility transition has advanced.

The decline of fertility has been accompanied by intensified spatial patterns. If one assumes that fertility decline results from external structural changes, which rarely follow a distinct spatial pattern, one would expect spatial structuring to weaken during fertility transition. The evidence points to the reverse. This suggests diffusion of fertility behavior across adjacent areas independent of other factors.

Appendix: Statistical and geostatistical estimation procedures

Child–woman index: Mortality correction and standardization

Two different child–woman ratios are used:

$$CWR(0–4) = Children(0–4) / Women(15–49)$$
$$CWR(5–9) = Children(5–9) / Women(20–54)$$

The first CWR is used for the quinquennium preceding each census, while the second CWR refers to the previous quinquennium. For instance, age data from the 1961 census provide CWRs referring to 1956–61 and 1951–56.

A major distortion in the use of these raw CWRs for estimating fertility trends arises from variations in infant and child mortality levels over time that affect differentially the surviving child population. As mortality is reduced, changes in raw CWRs reflect the joint effect of fertility and mortality changes.[26] The impact of mortality tends, however, to be relatively modest. A simple illustration might be useful in order to assess the impact of mortality variations on CWRs. Consider a stable population with a life expectancy of 55 years (West model) and a net reproduction rate of 2.24 (Coale and Demeny 1966). This approximates the average conditions in India during the period under study. Let each of the two types of CWRs for the reference stable population be equal to 100.0. Keeping the fertility level constant, we may compute CWRs for stable populations with different mortality levels. Table A-1 shows that in stable populations, a one-year increase in life expectancy would result in an increase of 0.5–0.6 percent in the two corresponding CWRs. A five-year increase in life expectancy, which is the average rate of increase of life expectancy in India between two successive censuses, would result in an increase of 2.4 percent (CWR 0–4) and 2.9 percent (CWR 5–9).

This illustration shows that the impact of mortality on CWRs is limited. When comparison is restricted to a single intercensal interval period or to geographically neighboring areas, mortality seems to have a moderate impact on CWRs. However, mortality variations between populations over a 30-year period or between regions characterized by marked mortality differentials (such as low-mortality

Table A-1 Illustration of the effect of the level of mortality on child–woman ratios

	Life expectancy at birth				
	50	**54**	**55**	**56**	**60**
CWR(0–4)[a]	96.7	99.3	100.0	100.5	102.4
CWR (5–9)[b]	95.6	99.1	100.0	100.6	102.9

[a] Children aged 0–4 divided by women aged 15–49
[b] Children aged 5–9 divided by women aged 20–54
NOTES: Child–woman ratios shown in the table are computed using a stable population with various specified mortality levels (West model, female), and with fixed net reproduction rates of 2.24. The ratios are scaled by equating the values at e_0=55 to 100.

Kerala and high-mortality Uttar Pradesh) may have more serious consequences on fertility estimations, and it would be unwise to disregard mortality differentials altogether.

In order to correct for mortality change, we calculated a corrected set of CWRs by dividing the raw CWRs by the appropriate survival rate from birth to the corresponding age group. For example, the corrected CWR(5–9) is computed by dividing by L_{5-9} / 5, where L_{5-9} is taken from West model life tables of an appropriately chosen mortality model. Mortality estimates for 1970 and later dates were derived from the Sample Registration System, which has provided reliable life tables for Indian states since the 1970s.[27] For previous periods, we used estimates derived by Bhat from the census. We combined SRS and pre-SRS estimates of life expectancy for both sexes by fitting a trend line from 1951–61 to 1992–96 for each state.[28]

State-level life expectancy estimates are shown in Table A-2.[29] Examination based on a Lexis graph shows the reference years for mortality-corrected CWRs to be 1.25 years before the census year for the age group 0–4 years and 3.75 years before the census year for the age group 5–9 years.

A further difficulty is that the two types of CWRs are not exactly comparable (see also Figure 2). For example, the average values for CWR(0–4) and CWR(5–9) are 0.727 and 0.917 after mortality correction. The gap between the two types of CWRs is linked to different factors such as the specific denominator values (females aged 15–49 and 20–54 respectively) and the differential quality of age enumeration among the 0–4 and the 5–9 age groups in India. This last factor is especially important, because the proportion of children below age 5 years is known to be systematically underestimated while the population aged 5–9 years is overestimated.

TABLE A-2 Estimates of life expectancy at birth for India and selected states, 1951–90

	1957	1960	1967	1970	1977	1980	1987	1990
India	41.4	42.8	46.8	48.2	52.2	53.6	57.6	59.0
Andhra Pradesh	37.6	39.3	44.5	46.3	51.5	53.2	58.4	60.1
Assam	37.5	38.8	42.8	44.1	48.1	49.4	53.3	54.7
Bihar	38.7	40.0	44.1	45.5	49.6	51.0	55.1	56.5
Gujarat	41.5	42.9	46.9	48.3	52.4	53.7	57.8	59.1
Haryana	44.0	45.4	49.7	51.1	55.3	56.7	61.0	62.4
Karnataka	39.7	41.4	46.6	48.3	53.5	55.3	60.4	62.2
Kerala	48.8	50.5	55.7	57.5	62.7	64.4	69.6	71.4
Madhya Pradesh	37.4	38.6	42.4	43.7	47.5	48.8	52.6	53.8
Maharashtra	40.3	42.1	47.4	49.2	54.5	56.3	61.7	63.5
Orissa	38.1	39.4	43.2	44.5	48.4	49.7	53.5	54.8
Punjab	47.6	49.0	53.2	54.6	58.9	60.3	64.5	65.9
Rajasthan	39.6	40.9	44.9	46.3	50.3	51.6	55.7	57.0
Tamil Nadu	38.7	40.6	45.7	47.4	52.5	54.3	59.4	61.1
Uttar Pradesh	31.6	33.4	38.6	40.3	45.5	47.3	52.5	54.2
West Bengal	37.4	39.1	44.5	46.2	51.5	53.3	58.6	60.4

NOTES: The states for which estimates are shown contain 95.8 percent of the population of India according to the census of 1991.
SOURCES: The estimated values are computed from trend lines based on estimates from Bhat (1987) and Registrar General of India (1999).

The method proposed here relies on direct standardization of the mortality-corrected CWRs and on limited smoothing.[30] Standardization is done independently for each CWR using the grand average of the mortality-corrected CWR for all available values (districts for all censuses). Because of this standardization, CWR is now an index centered on 1.

Standardized CWR = mortality-adjusted CWR/ $\text{average}_{1961\text{–}91}$(mortality-adjusted CWR). Smoothing of the standardized CWR values is then performed by a moving-average technique using weights 1/4, 1/2, and 1/4.[31]

$$\mathrm{CWR}(t) = [\ \mathrm{CWR}(t\text{–}5) + 2 \times \mathrm{CWR}(t) + \mathrm{CWR}(t+5)\ ] / 4$$

District units that have appeared (or disappeared) during the 1951–91 period had to be excluded from our sample since smoothing on a limited set of values was likely to oversimplify fertility trends during the period under study. We have kept only districts present during at least three consecutive censuses. Districts that have changed names or lost territories (to newly formed district units), however, have been retained. This procedure yielded data for 338 districts, while the total number of districts in our database increased steadily from 317 in 1961 to 450 in 1991.

We call the resulting mortality-adjusted, standardized, and smoothed fertility index the child–woman index (or CWI). The CWI estimates provide the first-ever continuous series of a fertility index for Indian districts for the period 1951–91. These are available from the authors upon request. This index could be further improved through more precise mortality corrections,[32] but our experimentation with various correction techniques indicates that further refinements are unlikely to yield significantly improved estimates of changes and differentials in district-level fertility.

Geostatistical procedures: Kriging and spatial autocorrelation

In this article we used a standard geostatistical technique called kriging to interpolate a continuous surface (India) from a sample of observations (a fertility index estimated for district headquarters). The method was developed by D. G. Krige and Georges Matheron in the 1960s and is described in detail in Bailey and Gatrell (1995) and in Haining (1990). A kriged estimate is a weighted linear average of the known sample values around the point to be estimated. In our case, we aggregated districts whose headquarters was less than 20 km distant (which is also the size of our grid). Because our geographical coordinates correspond to district headquarters and not to their geometrical centers, this aggregation has proved very useful; in some cases such as the Kolkata region, district headquarters can be in close proximity while corresponding districts are comparatively distant. Because of our smoothing, the observed semivariance for the smallest distance (less than 50 km) is almost zero and kriging acts as an exact estimator.

The method used in this article (ordinary kriging) assumes that the data have not only a stationary (or constant) variance but also a non-stationary mean value within the search radius limited to the 20 nearest districts. This method does not allow for the estimation of local values in edge areas situated beyond locations for which CWI values are available. For this reason no estimate is available for some border areas such as North Kashmir and West Gujarat.[33]

Spatial autocorrelation describes how an attribute such as fertility levels is distributed over space and to what extent the value observed in one zone depends on the values in neighboring zones. In this article, spatial correlation is computed with Moran's *I* coefficient.[34] This coefficient is based on correlograms, that is, graphs of spatial autocorrelation (y-axis) between pairs of observations classified by distance (x-axis). Moran's *I* coefficient is a standard measure of spatial autocorrelation, roughly analogous to the correlation coefficient used for ordinary regression analysis. For a given distance, the Moran coefficient of spatial autocorrelation is computed for a variable *z*:

$$I = \frac{\sum_{i,j} \left(z_i - \bar{z}\right)\left(z_j - \bar{z}\right)}{n \sum_i \left(z_i - \bar{z}\right)^2}$$

for *n* pairs of locations *i* and *j* such as distance $(i, j) = h$

When the Moran coefficient is computed for a variety of distances *h*, we get a correlogram showing the trend in spatial autocorrelation with respect to distance, with $I = 1$ when the correlation is perfect between observations. In Figure 7, the average distance between pairs of observations is used to plot spatial autocorrelation of raw CWRs.

Notes

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1 On European and Soviet fertility decline, see Coale and Watkins (1986) and Jones and Grupp (1987).

2 For recent explanatory models of Indian fertility down to the district level, see Malhotra, Vanneman, and Kishor (1995); Murthi, Guio, and Drèze (1995) for 1981 data and Bhat (1996) for 1991 data.

3 Matheron (1970) pioneered the concept of regionalized variables. See also Houlding (2000).

4 On Kerala, see Krishnan (1976); Zachariah (1984); Bhat and Irudaya Rajan (1990); Zachariah and Irudaya Rajan (1997); Nair (1974).

5 See Savitri (1994); Srinivasan (1995); Kishor (1994); Guilmoto and Irudaya Rajan (1998).

6 See, for example, Dyson and Moore (1983); Malhotra, Vanneman, and Kishor (1995).

7 See Kishor (1991); Malhotra, Vanneman and Kishor (1995); Murthi, Guio, and Drèze (1995); Drèze and Murthi (2001).

8 See Registrar General of India (1997); Bhat (1996); Irudaya Rajan and Mohanachandran (1998).

9 We have restricted ourselves to the years 1961–91 for several reasons. First, the 1951 administrative units, which followed closely the boundaries of British and Princely India, underwent radical changes during the 1950s. Moreover, 1951 data are incomplete and are not in all cases readily available for five-year age groups. Furthermore, the 1951 age distributions reflect fertility changes during the 1940s, a period that witnessed large-scale mortality crises in India (the Bengal famine among them). Fertility variations derived from the 1951 census are driven more by crisis and post-crisis recovery than by secular change and spatial heterogeneity.

10 This measure is computed by dividing the number of children under age 5 by the number of women between ages 15 and 49. By analogy, we can compute the ratio of children 5 to 9 to women 20 to 54. Both numerators and denominators are taken from census enumeration.

11 This method has often been applied to generate small-area fertility indexes in contexts where age distributions from regular censuses are available, but where births are not properly recorded. Child–woman measurements are more closely analogous to the general fertility rate (births per women of childbearing age) than to total fertility rates.

12 We have assessed the quality of age data and of the child–woman ratio, using the raw as well as the corrected (smoothed) age distributions for the four censuses, 1961 through 1991. The error on account of age misstatement is here computed as the relative difference between the CWRs calculated from raw data and the CWRs calculated from corrected data. For the CWR computed as children(0–4) / women(15–49), the percent of error stood at 9 percent in 1961, fell to 2 percent in 1971, and hovered around 5 percent between 1981 and 1991. However, for the CWR computed as children (5–9) / women(20–54), the picture is quite different. The percent error was 6 in 1961, increased to 14 in 1971, and fell markedly to 3 in 1981 and to less than 1 percent in 1991.

13 For reasons explained in the Appendix, we excluded some district units with incomplete data series.

14 One of the few studies on this period is Anderson (1974). See also Chakraborty (1978).

15 A more detailed mapping of fertility during the 1960s would show Coimbatore and Madras regions in Tamil Nadu, as well as Alappuzha in Kerala, to be the forerunners of this decline. Although these areas are not far apart, they nevertheless belong to different states and are separated by several districts.

16 For historical reasons, coastal areas in India have long been especially permeable to external influences. They constitute peripheral areas, very distinct from the central core of India. See Sopher (1980).

17 About the Khanna study, see Wyon and Gordon (1971) and Mamdani (1972). Das Gupta (1995) stated that fertility began declining much earlier in several parts of the Punjab, although our estimates do not support this early decline.

18 We have used here a procedure known as the k-means method, which minimizes the within-group sum of squares in each cluster (see Bailey and Gatrell 1995).

19 Reasons for such erratic fertility profiles may include actual demographic conditions, changes in district boundaries, or an especially poor enumeration record.

20 The pattern contrasts with the much more fragmented map of estimated dates of fertility decline in Europe (Coale and Watkins 1986: map 2.1).

21 In 1971–73, rural fertility rates were respectively 13.8 percent, 31 percent, and 38 percent higher than urban rates in Kerala, Punjab, and Tamil Nadu, as against 32.5 percent in India as a whole. In 1989–91, the rural–urban gap decreased to 18 percent, 0 percent, and 20 percent in Kerala, Punjab, and Tamil Nadu, while it increased to 48 percent in India as a whole. SRS data are from the compendium published by the Registrar General of India (1999).

22 See estimates by Bhat (2000). On fertility decline among illiterates, see also Arokiasamy, Cassen, and McNay (2001).

23 In spatial analysis, this situation corresponds to the existence of “barriers.” For a classic study of spatial diffusion, see Cliff et al. (1981).

24 One of the highest-fertility spots (in Uttar Pradesh) is depicted in Jeffery and Jeffery (1997). For a recent example of path dependency analysis applied to birth control history, see Potter (1999).

25 For some applications, see Bocquet-Appel, Courgeau, and Pumain (1996) and Airlinghaus (1996). See also Fotheringham and Rogerson (1994).

26 Because mortality rates are much lower among women, we believe that inter-district variations of female adult mortality rates are unlikely to disturb the values for the denominator.

27 Some district-level mortality estimates are available from the 1981 and 1991 censuses (Registrar General of India 1989, 1997). These district mortality indicators are based on indirect estimation using the proportion of surviving children. Because of discrepancies between 1981 and 1991 estimates and between these sources and regional SRS estimates, we considered it unwise to use these estimates to compute life expectancy values for 1951–91.

28 Life expectancy estimates for 1951–61 and 1961–71 are found in Bhat (1987). SRS estimates for 1970–75, 1976–80, 1981–85, 1986–90, 1991–95, and 1992–96 are from Registrar General of India (1999). For census estimates prior to 1971, see also Agarwala (1985).

29 For states for which no mortality estimate is available, we used mortality levels of the closest state or the all-India level. Tamil Nadu values are applied to Pondicherry, all-India averages to northeast states, and so on.

30 For another application of the method to Indian historical data, see Guilmoto (1992: 76).

31 To smooth extreme values for 1951–55 and 1986–90, we applied the average smoothing factor as obtained respectively for CWR2 and CWR1.

32 To name a few possible refinements: correcting for adult mortality, using different model life tables, accounting for different mean age at childbearing.

33 Because the census was not held in Kashmir in 1991 owing to political turmoil, the area with no estimate is even larger in the two maps shown for the 1980s.

34 On spatial autocorrelation, see Bailey and Gatrell (1995) and Fotheringham, Brundson, and Charlton (2000).

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