Original Research Article

Testing Three Evolutionary Models of the Demographic Transition: Patterns of Fertility and Age at Marriage in Urban South India

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ABSTRACT Over the last three decades many authors have addressed the demographic transition from the perspective of evolutionary theory. Some authors have emphasized parental investment factors such as the costs of raising children, others have emphasized the effects of mortality and other forms of risk, and others have emphasized the biased transmission of cultural norms from people of high status. Yet the literature says little about the relative strengths of each of these types of motivations or about which ones are more likely to serve as the primary impetus for large-scale demographic change. In this paper, I examine how each of these factors has influenced the demographic transition in urban South India during the course of the 20th century using two measures of fertility transition: number of surviving children and age at marriage. I find that investment-related, risk-related, and cultural transmission predictors all have significant individual effects on the outcome variables, which persist when they are entered in combination. When the three types of predictors are compared, however, investment-related models appear to provide more robust explanations for patterns in both fertility and age of marriage. Am. J. Hum. Biol. 21:501–511, 2009.

Much research has been done on the causes and consequences of the demographic transition, a global phenomenon whereby high fertility and mortality rates are gradually replaced by low fertility and mortality rates over the course of decades or centuries. Though some authors have argued that early stages of the transition took place in Imperial Rome (or other ancient complex societies), the earliest agreed-on instances date from 18th and 19th century Europe (e.g., Caldwell et al., 2006; Chesnais, 1992). The phenomenon did not become widespread until the 20th century; however, during this period, many parts of the world underwent major reductions in both mortality and fertility (e.g., Caldwell et al., 2006; Chesnais, 1992). The scientific literature usually links the demographic transition to economic development, but the exact mechanisms that motivate it are the subject of much interdisciplinary debate (e.g., Caldwell et al., 2006).

The demographic transition was once called the “fundamental problem of human sociobiology” (Vining, 1986, p 167) in that it presents two key problems for evolutionary theory. In postdemographic transition societies, (1) observed fertility is lower than what would be expected by models of fitness maximization, and (2) wealthier people produce no more children than poorer people. Much work has been done since Vining’s time to try to reconcile (or at least explain) this apparent disconnect. Most work by evolutionary theorists considers modern low fertility as a response to either (a) changing ecological cues that affect relationships between parental investment and offspring outcomes or (b) changing parental motivations for fertility per se. Many authors see modern fertility patterns as maladaptive but consistent with motivations which would have been adaptive under ecological conditions found in most premodern societies (e.g., Kaplan, 1996; Kaplan and Lancaster, 2000; Low, 2000; Mace, 1998).

Within the evolutionary literature, there are three primary themes regarding the causal mechanisms thought to motivate people to reduce their fertility. Some authors have emphasized motivations related to changing motivations for parental investment, including increased costs to child rearing or increased competition in highly stratified modern social environments (e.g., Kaplan, 1996; Low, 2000; Low et al., 2002; Luttbeg et al., 2000; Mace, 1998, 2000). Other authors have emphasized motivations related to the reduction of mortality rates and/or other forms of extrinsic risk (e.g., Chisholm, 1993, 1999; Leslie and Winterhalder, 2002; Quinlan, 2006, 2007; Quinlan and Quinlan, 2007; Winterhalder and Leslie, 2002). A third set of authors has focused on the importance of cultural transmission influencing behavior in maladaptive ways in novel modern environments (e.g., Boyd and Richerson, 1985; Richerson and Boyd, 2005). The literature says little, however, about the relative strengths of each of these motivations or about which are more likely to serve as the primary impetus for large-scale demographic change.

In this paper, I explore how investment-related, risk-related, and culturally transmitted motivations may have influenced the demographic transition in Bangalore, India, over the course of the 20th century. To do so, I focus on two primary indicators of the demographic transition: the age at which women are first exposed to the possibility of reproduction, and the number of surviving children they bear. I find that all three types of motivations are strong predictors of these indicators, but that from a comparative perspective investment-related models provide broader and more robust explanations than other models for the demographic transition in South India.

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Three evolutionary models of the demographic transition

The theoretical literature from evolutionary anthropology on the topic of the demographic transition identifies several types of motivations, which may be important in predicting demographic transitions. This section provides an overview of each group of models as well as the patterns of fertility, age at first reproduction, and sequential timing of demographic change predicted by each.

Parental investment and the cost of children. Many authors have stressed the importance of increased investment in oneself or one's children, or the related concept of increasing costs of children, as primary factors in decreasing either optimal fertility or age at first reproduction. Kaplan (1996) argues that payoffs to investment in child quality determine parental decisions about the number of children to have. In comparison to the returns expected in many traditional societies, Kaplan maintains that returns to parental investment in wage-labor economies do not diminish until very high levels. In consequence, per-child investment should be expected to increase, and optimal fertility to decrease, producing a demographic transition. In addition, parents with higher levels of investment themselves (particularly in the form of education) will be more effective at investing in their own children, thus benefitting from higher payoffs and having lower optimal fertility than parents not so well-endowed. This reasoning implies that high payoffs should precede fertility reduction, and Kaplan predicts that they may also spark demand for or uptake of contraceptives.

A dynamic model published by Mace (1998) compared the effects of changes in several predictors on fertility. She found that increasing the costs of raising children led to a decrease in optimal fertility, and in fact had the potential to reduce fertility to very low levels. Increasing wealth or decreasing risks to children did not have similar effects. Expanding this argument in a later article, Mace concludes that "increasing parental investment in children is the key to decreases in fertility" (Mace, 2000, p 274). Luttbeg et al. (2000) use dynamic modeling and data on the pastoral (and pre-demographic transition) Kipsigis to argue that material motivations are important in humans even in highly pro-natal societies where wealth is strongly correlated with fertility. They suggest that humans may be maximizing a combination of reproductive and material success rather than reproductive success per se. Finally, Low et al. (2002) argue that the demographic transition is linked to increased investment in socioeconomic status through mediums such as education and work; this leads to increased ages at first reproduction and thus to lower lifetime fertility.

Collectively, I will refer to the models and motivations discussed here as 'investment-related.' Drawing on the work of these authors, an investment-related perspective allows us to make several predictions regarding the demographic transition, which can be tested with data from the Bangalore dataset:

1. Higher levels of investment in parent and/or child should be associated with lower fertility and later ages of first reproduction.
2. Fertility decline should be preceded by access to formal education and/or a wage-labor job market.
3. Fertility decline should precede widespread availability of contraceptives.

Risk and mortality. Other authors have stressed the importance of decreasing risk, especially mortality risk, as a primary factor in decreasing optimal fertility and age at first reproduction. In this literature, risk is defined as "any unavoidable factor that can reduce an organism's reproductive value" (Quinlan, 2007). Risk-related work on fertility and fertility transition has been developed and discussed most notably by Chisholm (1993, 1999), Leslie and Winterhalder (2002), Quinlan (2006, 2007), and Winterhalder and Leslie (2002).

Chisholm (1993) argues that human reproductive strategies may be contingent on local mortality rates such that those who experience more loss as children are more likely to pursue mating-oriented reproductive strategies, which may result in earlier and higher fertility, while those who experience a lower mortality environment may delay reproduction or pursue a strategy of high parental investment. Quinlan (2006, 2007) and Quinlan and Quinlan (2007) discuss the effects of extrinsic (noncare-dependent) forms of risk on parental investment decisions using data from Dominica as well as comparative data from the standard crosscultural sample. They argue that "humans should show reduced parental effort in environments where parenting cannot improve offspring survival" (Quinlan, 2007, p 121) and, by implication, that if extrinsic risk decreases then parental effort should increase and fertility should decrease with it. Leslie and Winterhalder (2002; see also Winterhalder and Leslie, 2002) stress the importance of risk sensitivity in shaping fertility behavior, with a special focus on stochasticity in mortality patterns. While predictions from their model are context sensitive, they argue that in general lower or more predictable mortality would decrease variance in completed family size outcomes and thus reduce the tendency of families to overcompensate by having numerous offspring. They also suggest that mortality decline has likely been a precondition of fertility decline.

While these models suggest that levels and types of risk affect motivations for parental investment (and so in some sense are also parental investment models), they emphasize changes in risk as the causal determinant of changes in reproductive behavior. Thus, to distinguish them from the models discussed previously, I will collectively refer to the models and motivations discussed here as 'risk-related.' Drawing on the work of these authors, a risk-related perspective allows us to make two general predictions regarding the demographic transition, which can be tested with data from the Bangalore study population:

1. Higher levels of mortality or other forms of risk will be associated with higher fertility and earlier ages at first reproduction.
2. Decreases in rates of mortality or other forms of risk will precede fertility decline.

Cultural transmission. Boyd and Richerson (1985) and Richerson and Boyd (2005) have argued that the demographic transition is a consequence of cultural transmission, a Darwinian but nongenetic mechanism

TABLE 1. Summary statistics

Variable	Mean	Standard deviation	*N*	Low	High
Outcome variables					
Number of surviving children	2.72	1.36	620	1	10
Bride's age at marriage	20.36	4.36	1,190	8	36
Predictors					
Mother's years of education	9.47	5.62	1,190	0	19
Infant mortality rate	43.79	16.93	1,190	24	133
Number of family planning clinics	392.8	109.15	1,190	37	500
Controls					
Husband's monthly income	17,810	150,313	1,190	25	5,000,000
Girls minus boys	−0.14	1.69	620	−5	5

of inheritance, which may sometimes select for traits that are socially successful but genetically maladaptive. The authors suggest that humans have evolved to preferentially imitate the behaviors of people of high social status (a pattern they call *prestige bias*), which in the past would usually have led to increased reproductive success. In modern industrial societies, however, social and reproductive success have become decoupled, even antagonistic, such that the achievement of high status usually means trading off one's own reproduction for the production of prestige. If high-status people have low fertility norms yet their behavior is still preferentially imitated, widespread fertility reduction could result regardless of its negative effect on individual fitness. The authors also argue that other models, such as that of Kaplan (e.g., Kaplan, 1996), are less parsimonious, since they suggest that the decision-making rules that humans use to adjust fertility would have been adaptive most of the time, whereas the Boyd and Richerson model suggests that "as soon as cultural transmission became significant, selection on cultural capacities would have begun to favor nonparental transmission, and, inevitably, rogue cultural variants would appear" (Richerson and Boyd, 2005, p 189). In other words, disconnects between cultural and genetic success are to be expected, and are an old, rather than a novel, aspect of human behavior.

Drawing on the work of these authors, a cultural transmission perspective allows us to make the following predictions regarding the demographic transition, which can be tested with data from the Bangalore study population:

1. Higher levels of exposure to status-related norms of low fertility will be associated with lower fertility and later ages at first reproduction.
2. Exposure to low fertility norms will precede widespread fertility decline.

DATA AND METHODS

Study population

The data used in this article were collected in Bangalore, India, in 2001–2002. The capital of the state of Karnataka, Bangalore, is a city of ~5.7 million people located in India's south central Deccan plateau (Haub and Sharma, 2006). The city underwent extensive development during the 20th century culminating with especially rapid growth from the 1990s to the present in connection with the boom in India's technology sector. The city has also undergone both aspects of demographic transition, with census data indicating that fertility rates in the area dropped from more than six children per woman to just over two between 1900 and 2000 while mortality rates decreased by as much as 75% during the same period (Government of Mysore, 1951, 1959–1970; Sekhar et al., 2001).

Data collection included detailed interviews with 403 respondents between the ages of 45 and 70. The protocol and procedures employed in collecting this data were reviewed and approved by the University of Washington institutional review board. Respondents were recruited through personal contacts and referrals by snowball sampling (Bernard, 1995). This was the only feasible way of collecting detailed data as enumerated lists of residents are rare and problematic and a personal introduction is often necessary to secure an interview of any depth. Interviewees came from a broad range of social classes and from all major caste groups in Bangalore. The interviews collected data on the demographic and socioeconomic characteristics of the respondent's family, the natal families of the respondent and his/her spouse, and the families of the respondent's adult children. Fertility data come from three generations of a family, with grandmothers born in the early part of the 20th century and granddaughters born in the later part.

Data and variables

This paper will focus on two outcome variables: *number of surviving children* (often used as a measure of reproductive success) will be used as a proxy for fertility and *age at marriage* will be used as a proxy for age at first reproduction. Summary statistics for all variables can be found in Table 1. Because of the larger sample sizes at later dates, most averages are skewed toward the more recent portion of the sample.

Number of surviving children. The dataset does not include accurate infant and child mortality measures; so, giving the total fertility rate (TFR) is not possible. However, the dataset does include very accurate information on the number of children who survived childhood. Respondents were women who had completed fertility and were asked to report children surviving beyond age 5; however, for cultural reasons, many did not mention any children who died before age 10. For evolutionary studies, this measure is more relevant than the TFR, since infant and child mortality have already been accounted for, and given the Indian emphasis on universal marriage, each remaining child has a very high likelihood of reproducing. Figure 1 shows the average number of surviving children

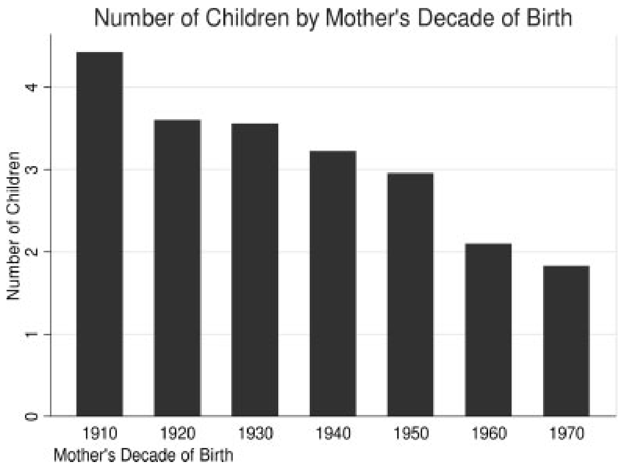

Fig. 1. A woman's average number of surviving children organized by her decade of birth (women born after 1972 or women married less than 10 years excluded), showing evidence of a demographic transition over the course of the 20th century in Bangalore.

by the decade of their mother's birth. The sample was restricted to include only (a) women born in or before 1972, who were at least 30 at the time of the survey, and (b) women who had been married at least 10 years at the time of the survey. Women who did not meet these criteria were excluded, as they were not likely to have completed their fertility. Women with no children were excluded from this analysis because they are rare (less than 1% of the sample of women over 35), and usually do not have children for reasons not related to fertility decision-making (e.g. not being married due to a disability, being married very recently, having a rare type of primary sterility).

Age of first reproduction. The dataset does not include good quality data on age of first reproduction, but it includes excellent data on age at marriage for most of the women in the sample. This information was elicited directly from the respondent, and in the few cases, where it was not given, it could usually be realistically estimated using year of marriage and year of birth. Age at marriage in this sample increased from an average of 17.4 years for women born in the 1920s to an average of 22.2 years for women born in the 1970s. Additionally, age of marriage is a very good estimator of age of first reproduction in India, since two-thirds of first births occur between 18 and 30 months after marriage (Chandrasekhar, 1972). For reliable data in my sample, the average time from marriage to first birth is 2.2 years (standard deviation 1.5 years, $N = 285$) among women married at age 14 or older.

Investment predictor. To test predictions about parental investment motivations for the demographic transition, I will use the variable *mother's* (*or bride's*) *years of education*. While one could potentially use other measures, there are several good reasons to use this variable. First, many of the investment-related models discussed above identify education as a primary attribute involved in the increase in personal or parental investment in modern economies (e.g., Kaplan, 1996; Low et al., 2002). Second, the continued education of reproductive-aged women is thought to produce an explicit tradeoff with early and high fertility, and much demographic literature links a mother's education to a reduction in her fertility (e.g., Caldwell et al., 2006). It should be noted, however, that in this population the tradeoff takes place before marriage since women usually delay marriage to finish their educations and almost never continue their studies after they are married and at risk of childbearing. Third, a mother's education is predicted to be associated with the amount of investment she makes in her own children (e.g., Kaplan, 1996). Finally, the education of a woman is often strongly correlated with educational or skill-based measures of her close relatives and thus is likely to serve as a reasonable proxy for the educational attributes of the family more broadly.

Risk predictor. The dataset does not contain high-quality individual-level risk or mortality data; thus, risk-related predictions will be tested using aggregate data from the Indian census. To test risk-related predictions, I will use the infant mortality rate at the bride's year of marriage. The infant mortality rate is the number of infants per 1,000 born who die in their first year of life (e.g., Hinde, 1998). Infant death rates are usually higher than those for other age groups because infants are more susceptible to mortality from a wide variety of causes, including disease, poor nutrition, and inadequate care. Their vulnerability also makes them barometers of conditions for children and adults in a society, since infant mortality rates are usually strongly associated with mortality rates at later ages. For these reasons, the infant mortality rate is considered a key development indicator globally and is often used as an indicator of the general level of risk in a society (e.g., Chandrasekhar, 1972; Sekhar et al., 2001).

Good estimates of infant mortality exist for Karnataka state from 1924 to 1964 (Chandrasekhar, 1959, 1972) and from 1971 to 1999 (Sekhar et al., 2001). Good estimates for the years before 1924 could only be found for India on the national level (Chandrasekhar, 1959), but these apply to relatively few members of the sample. Using the best estimates at different time periods and a small amount of interpolation, I was able to construct a set of infant mortality rates spanning the 20th century. The crude death rate for adults tracks the infant rate very closely although the absolute levels are much lower (e.g., Government of India, 1960–1981; Government of Mysore, 1951, 1959–1970; Sekhar et al., 2001).

Cultural transmission predictor. I will use the number of family planning clinics in Karnataka state at the bride's year of marriage as a proxy for the level of cultural transmission of low-fertility behaviors in Bangalore. Prior to the 1940s only one explicit family planning clinic existed in Bangalore (Potts and Campbell, 2002); however, abortions were sometimes performed at maternity hospitals or women's clinics (Government of Mysore, 1951). Beginning in the 1950s, the number of family planning clinics grew quickly as a result of explicit government programs to encourage fertility reduction (National Commission on Population, Government of India, 2008). These policies were accompanied by educational programs and advertising

TABLE 2. Results for number of surviving children

Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	1.009***	−0.613***	1.293***	0.870***	0.8687***
Mother's education	−0.063***			−0.050*** (−0.243)	−0.0502*** (−0.243)
Infant mortality rate		0.020***		0.007** (0.169)	0.0077** (0.169)
Family planning clinics			−0.002***	−0.001*** (−0.172)	−0.0013*** (−0.175)
Husband's income[a]					−0.0004 (−0.011)
Girls minus boys					0.0222 (0.028)
AIC	1,872.9	1,915.0	1,900.4	1,814.5	1,816.7
ΔAIC	0	42.1	27.5		
AIC weight	1	0	0		
ΔAIC	58.4	100.5	85.9	0	2.2
AIC weight	0	0	0	0.75	0.25

Generalized linear regression results for nested models showing the effects of predictors (mother's education, infant mortality rate, and family planning clinics) and controls on the dependent variable *number of surviving children*. The dependent variable is modeled using a Poisson distribution. Standardized betas are in parentheses. $N = 620$.
Significance is indicated as follows: ***<0.001, **<0.01, *<0.05.
[a]Husband's income is measured in thousands of rupees per month.

campaigns, which encouraged the ideal of small families and the adoption of contraception (Pathak et al., 1998). As the campaigns ramped up, so did the number of family planning clinics and the availability of contraceptives; thus, the availability of family planning clinics directly tracks the importance of the limitation of family size, as it was perceived by and communicated by the elites who controlled governmental policies and had usually already adopted such behaviors themselves. The number of clinics thus provides a proxy for the degree of exposure to these ideals and messages among the general public.

Data on the number of maternity hospitals in Karnataka state were obtained for 1923–1944 (Government of Mysore, 1951), and the number of family planning clinics in Karnataka state for most years from the 1950s through 2002 (Government of Karnataka, 1998–2001; Government of Mysore, 1959–1970; Government of India, 1960–1981). Using the appropriate data at each time period and some interpolation, I constructed estimates of the number of family planning clinics each year for the period 1923–2002.

Analyses

Generalized linear models (GLM) are used to allow for different outcome variable distributions as well as a single format for maximum likelihood estimation. Number of surviving children is a count variable with a long right tail so it is modeled using a Poisson distribution, while age at marriage is normally distributed and is modeled using a Gaussian distribution. Parameter estimates and significance are interpreted in the same way as ordinary regression models and can be used for hypothesis tests.

In addition, maximum likelihood estimation is used to generate Akaike's Information Criterion (AIC) values, which allow for comparison between models. The goal of the AIC method is to find the model that best explains the data with a minimum number of variables. Within a set of models tested, the preferred model is the one with the lowest AIC value (Anderson et al., 2000; Towner and Luttbeg, 2007).

RESULTS AND DISCUSSION

The demographic transition in Bangalore

Before answering the question of why a demographic transition occurred, we first need to establish that one did. Figure 1 (above) shows a clear downward trend in the number of surviving children over time in the Bangalore sample. A regression on the dependent variable *number of surviving children* shows that a woman's year of birth is a highly significant negative predictor (beta = −0.040, $P <$ 0.000); in addition, census figures show that the overall reduction has been more than four children per woman, with a total fertility rate of over six in Karnataka state in the early 20th century (Government of Mysore, 1951) declining to 2.0 in Bangalore city by 1998 (National Commission on Population, Government of India, 2008). The reduced number of children per woman has been accompanied by an increase in the age at marriage in the Bangalore sample from an average 17.4 among women born in the 1920s to an average of 22.2 among women born in the 1970s. A regression on the dependent variable *age at marriage* shows that a woman's year of birth (beta = 0.027, $P = 0.041$) and year of marriage (beta = 0.137, $P < 0.000$) are both significant predictors, though year of marriage is better as should be expected.

In addition, both of the biologically novel aspects of the demographic transition are present in 20th century Bangalore. First, fertility has decreased at a time when real incomes in India have risen or stayed the same (Roy, 2000; Williamson and Zagha, 2002). Second, the relationship between wealth (as measured by husband's income) and fertility (as measured by a woman's number of surviving children) is negative and significant (beta = −0.012 for every 1,000 rupees of monthly income, $P = 0.001$).

Number of surviving children

Analyses for the outcome variable number of surviving children are illustrated in Table 2, which confirms that results for all predictor variables are in the hypothesized direction. Table 2 clearly shows that in Bangalore mothers with more education have fewer children. More specifically, mothers with 0–5 years of education have an average of four children, whereas women with 12 or more years of education have on average two children. Table 2 also illustrates a strong, positive relationship between the infant mortality rate and the number of surviving children, and a strong negative relationship between the number of family planning clinics and the number of surviving children. When all predictors are entered together the effect sizes are reduced but significance is maintained for all three. The full model includes controls for husband's income (to remove the effects of wealth) and for a

TABLE 3. Results for age at marriage

Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	16.455***	24.585***	14.434***	16.170***	0.1616***
Bride's education	0.412***			0.347*** (0.352)	0.3460*** (0.350)
Infant mortality rate		−0.097***		−0.031** (−0.117)	−0.0311** (−0.113)
Family planning clinics			0.015***	0.006*** (0.134)	0.0058*** (0.135)
Husband's income[a]					0.0005 (0.009)
AIC	6,496.3	6,709.1	6,706.6	6,404.9	6,406.3
ΔAIC	0	212.8	210.3		
AIC weight	1	0	0		
ΔAIC	91.4	304.2	301.7	0	1.4
AIC weight	0	0	0	0.67	0.33

Generalized linear regression results for nested models showing the effects of predictors (bride's education, infant mortality rate, and family planning clinics) and controls on the dependent variable *age at marriage*. The dependent variable is modeled using a Gaussian distribution. Standardized betas are in parentheses. N = 1,190. Significance is indicated as follows: ***<0.001, **<0.01, *<0.05.
[a]Husband's income is measured in thousands of rupees per month.

variable which subtracts the number of sons from the number of daughters (serving as a control for the sex ratio of children in the family). The addition of these controls has very little impact on the effect size or significance of the predictor variables, and neither of the controls is significant itself. Controls for bride's age at marriage and the log of the husband's income did not affect the model and thus were not included; a control for mother's year of birth was considered but presented multicollinearity problems and would have reduced the variance in the dependent variable that this paper is trying to explain.

When the three bivariate models are compared using AIC values, it is clear that a mother's education is a much better individual predictor of her number of surviving children than either the infant mortality rate or the number of family planning clinics alone; the AIC weights give 100% probability that mother's education alone is the best model. However, when AIC values are compared across all models, the three-predictor multivariate model does better than any single predictor alone. The AIC weights give a 75% probability that the three-predictor model is the best overall model and a 25% probability that the multivariate model with controls is the best. The bivariate models do not compare well enough to have any weight.

Standardized coefficients, shown in parentheses beneath the unadjusted coefficients, are calculated by running the same analysis on variables adjusted to have variances of one. Standardizing makes coefficients comparable across variables of different units, and standardized coefficients are commonly used to show the relative effects of each predictor on the outcome variable (e.g., Kleinbaum et al., 1988). In both multivariate models, it is clear that the effects of infant mortality rate and number of family planning clinics are quite similar, but that the effect of mother's education is about 40% greater.

These findings imply that the notable decline in fertility in Bangalore over the course of the 20th century may be due to increasing investment (as represented by mother's educational levels), decreasing risks (as represented by infant mortality rates), and transmission of low-fertility norms (as represented by prevalence of family planning clinics and their associated public relations campaigns). Moreover, the evidence indicates that the effects of investment motivations are somewhat larger than the effects of risk motivations or cultural transmission. Taken together these results suggest that a full explanation of the demographic transition will not be offered by any predictor variable singly. It also suggests that the different types of causality are linked and that changes in one may be unlikely to take place without changes in the others.

The importance of a mother's education as a predictor of her number of surviving children is not simply due to a schooling-related delay. It is true that the effect of a bride's age at marriage on the number of her surviving children is negative and highly significant (beta = −0.098; P < 0.000). When entered jointly with mother's education, however, the significance of bride's age at marriage (standardized beta = −0.179, P < 0.000) decreases and is only about half the size of the effect of mother's education (standardized beta = −0.356, P < 0.000). These results suggest that while delaying marriage is an important proximate mechanism for reducing fertility, there is an additional and possibly more influential direct role for investment-related motivations. This finding contrasts that of Low et al. (2002) who found that the relationship between a mother's education and her fertility was primarily mediated by her age at first reproduction, but is consistent with work by Kaplan (1996) and Mace (1998, 2000), which suggests that education-related fertility reduction is strategic.

Age of marriage

The bivariate relationships between the three predictors and the outcome variable age at marriage are shown in Table 3. All three effects are statistically significant and in the predicted direction: more educated women have later ages at marriage, women were married earlier during periods of higher infant mortality rates, and a higher number of family planning clinics is associated with later ages at marriage. When all three predictors are entered together the effect sizes are reduced, but all three remain significant; the effect of infant mortality rate decreases the most. The full model includes controls for husband's income to remove the effects of wealth, but its presence has very little impact on the other variables. A time control such as mother's year of birth is not used for the reasons discussed above.

When the three bivariate models are compared using AIC values, as with the results for number of surviving children a bride's education is a much better predictor of her age at marriage than the infant mortality rate or the number of family planning clinics; the AIC weights give 100% probability that bride's education alone is the best model. When AIC values are compared across all models, the multivariate model including the three predictors

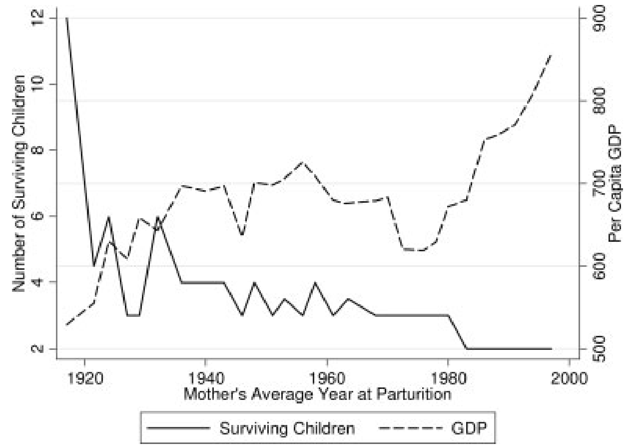

Fig. 2. Relationship between fertility change (number of surviving children) and economic development (GDP) from 1920 to 2000. The two variables appear to have a rough inverse relationship, suggesting that changing motivations for parental investment in formal education and wage-labor occupations may have driven the demographic transition in Bangalore.

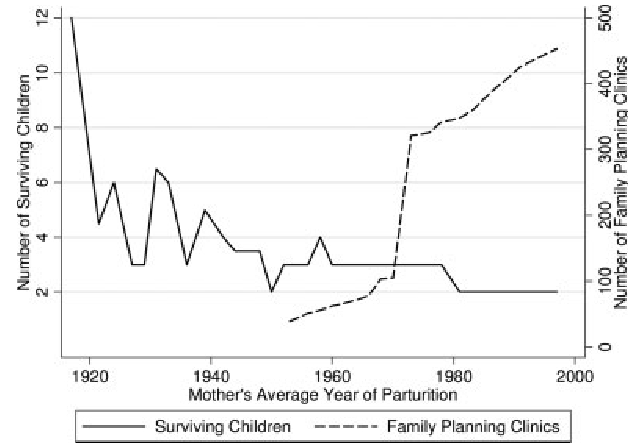

Fig. 3. Relationship between fertility change (number of surviving children) and access to contraceptive technology (number of family planning clinics) in Bangalore, India, from 1920 to 2000. Significant fertility reductions had already taken place before access to contraception became widespread, suggesting that cultural transmission of low fertility norms (at least through formal family planning programs an d education) were not the initial or primary cause of the demographic transition in Bangalore.

does better than any predictor alone. The AIC weights give a 67% probability that the three-predictor model is the best overall model of a woman's age at marriage and a 33% probability that the multivariate model with the husband's income control is the best. When the relative strengths of the investment and risk predictors are compared using the standardized coefficients, bride's education appears to be twice as strong a predictor of age at marriage as the infant mortality rate or number of family planning clinics, which are similar in magnitude.

Similar to the findings for number of children, these findings imply that the increase in age at marriage (and by implication age at first birth) in 20th century Bangalore may be due to the combined effects of increasing investment, decreasing risk, and the cultural transmission of low fertility norms. Yet again, however, there is evidence that investment motivations may be primary.

Fertility transition sequence

The three types of models of the demographic transition discussed above also produce predictions about the sequence of events during fertility transition. Given that age at marriage is only a proximate determinant of fertility, I will focus here on the number of surviving children. While the data do not lend themselves to detailed event history analysis, I can offer some simple sequential comparisons to test whether the Bangalore data are consistent with predictions offered by any of the models.

Economic development. The work of Kaplan (1996) and Low et al. (2002) suggests that fertility reduction should be spurred by economic development and access to wage-labor jobs. Figure 2, which shows the pattern of change in the Indian GDP in relation to fertility rates, indicates that this may have been the case in Bangalore. Increasing opportunities for upper caste Indians to obtain an English education and enter into civil service and other professions began in the early days of the British Raj, but expanded significantly in the late 19th and early-mid-20th centuries (Metcalf and Metcalf, 2006; Roy, 2000). Accompanying this were increasing opportunities for less privileged people to attend schools and take up nonagricultural work in factories or other businesses. This trend would have been quite noticeable in Bangalore, which at the time was a British military and administrative center and commercial hub. As predicted, during this period, fertility in Bangalore was steadily falling from an average of over five to six surviving children per woman to around three to four by the end of British rule in 1947.

After its independence, India adopted a centrally planned economy characterized by large-scale industrialization, which curtailed foreign investment and effectively limited internal economic activity under the arcane bureaucracy known as the 'License Raj' (Roy, 2000). The upshot of these measures was sluggish economic progress often derisively called the "Hindu Rate of Growth" in comparison to the fast growth rates of the nearby Asian Tiger countries (Williamson and Zagha, 2002). However, while economic growth was slow, the nation continued to urbanize and access to formal education and wage-labor jobs in cities like Bangalore increased (Williamson and Zagha, 2002). During this period, fertility decline in my sample matched the sluggish economy, remaining around three children per woman throughout much of the midcentury when the GDP hovered just under 700. In the early 1980s, serious financial difficulties at that national level spurred the passage of a set of economic liberalization and deregulation reforms, followed in 1992 by an even more comprehensive set of reforms (Williamson and Zagha, 2002). Beginning in the early 1980s, GDP has increased more quickly along with the pace of urbanization and the size of the nonagricultural employment sector. Matching the GDP growth was a rapid decline in fertility from three to two children per woman in Bangalore.

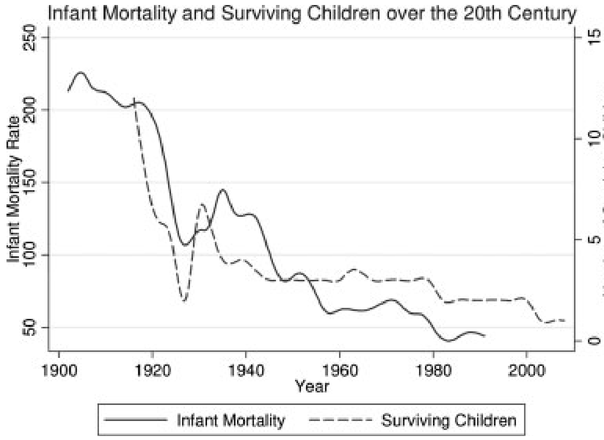

Fig. 4. A comparison of 20th century temporal changes in infant mortality rates and fertility in Bangalore, India. Decreases in the number of surviving children begin before decreases in infant mortality, suggesting that risk reductions may not have been the initial or primary cause of the demographic transition in Bangalore.

Contraceptive availability. Another prediction offered by Kaplan (1996) is that fertility reduction should precede the widespread availability of contraceptives—in fact, should drive demand for them. Alternatively, a cultural transmission perspective might suggest that the promotion of contraception by teachers and important culture figures (as happened in India alongside the expansion of family planning programs) might precede fertility decline. As Figure 3 shows, the former appears to have been true in Bangalore. Significant fertility declines (from over six to around four children per woman) had already begun when Mysore State began its first Family Planning Program in Bangalore in the early 1930s (Potts and Campbell, 2002), one of the first programs of its type in the developing world; services in Mysore were very limited and are not thought to have reached more than a very small fraction of the population. By the time that the Republic of India launched a national family planning program in 1952 (National Commission on Population, Government of India, 2008), surviving children had already declined to around three children per woman in Bangalore. With the creation of the Department of Family Planning in 1966, this initiative had grown to a large-scale national effort focusing primarily on nonreversible techniques such as tubal ligations and vasectomies (National Commission on Population, Government of India, 2008), which were adopted by some members of the population, forced on others, and resisted by yet others (Pathak et al., 1998). Thus contraceptives were still not adopted as widely as they might otherwise have been (Pathak et al., 1998). By the time reversible techniques such as oral contraceptives became commonly available in the late 1980s, fertility in my sample had already decreased to just over two children per woman.

Risk reduction. Risk-related models such as those of Chisholm (1993, 1999) and Leslie and Winterhalder (2002) suggest that reductions in rates of mortality and other forms of risk should precede reductions in fertility. As Figure 4 shows, however, this may not have been true in Bangalore, at least for risk measured in infant mortality rates and crude death rates (not shown). While the patterns of change in infant mortality rates (axis on the left) and number of surviving children (axis on the right) do sometimes parallel each other, the number of surviving children appears to fall (and rise) *before* the infant mortality rate changes, directly contradicting the notion of a decline driven by mortality reductions. While it is possible that this is an artifact of the way the surviving children line is constructed (by adding the average age at birth, 26 in this population, to the mother's year of birth), it would take raising the average age at birth to an unrealistically high 30 years to make the drop in infant mortality rates precede the drop in number of children. Thus, it is more likely that either the infant mortality rate fell along with the number of children or that the decrease in fertility spurred the decrease in the infant mortality rate. Instances of mortality rates falling after fertility rates have already decreased have been discussed by Cleland (1995), Chesnais (1992), and Mason (1997). They are also consistent with the work of Kaplan (1996) and Mace (1998) who argue that changes in fertility linked to increased investment may drive down mortality.

Interpretations and limitations

While the predictor variables used in this article were chosen carefully, they do not always have mutually exclusive interpretations. For instance, a woman's level of education might also be used as a measure of her exposure to status-related low-fertility ideals through either the people or the information she encountered in school. This would imply that a portion of the predictive strength of mother's or bride's education might be due to cultural transmission. Education, however, is the primary measure of investment in daughters, while it is only one of many possible cultural transmission mechanisms. This suggests that the investment aspect of education may be more important than the transmission element of education. In another example, the availability of contraceptives may be partly driven by people motivated to reduce fertility for other reasons (e.g., to be able to invest more per child) rather than those who are motivated to do so through cultural transmission. However, such a perspective does not account for the presence or effects of public awareness campaigns that accompanied the rise in family planning clinics in India.

Another potential limitation is that mother's and bride's education are individual-level variables, while the variables *infant mortality rate* and *number of family planning clinics* were derived from aggregate-level data. Regarding risk variables, however, it is not clear whether individual or aggregate-level risk data is ideal for testing theoretical predictions. Some authors suggest that risk cues are primarily taken from family members (e.g., Chisholm, 1999; Draper and Harpending, 1987), while others suggest that aggregate levels of risk at the village or population level may be used as cues instead of or in addition to family information (e.g., Quinlan and Quinlan, 2007). Until similar results are shown with individual-level data, however, the jury will remain out on which type of variable makes the more appropriate predictor for patterns of fertility reduction.

Likewise, individual levels of exposure to high-status, low-fertility norms might seem more ideal for predicting individual fertility and marriage timing behaviors, but they would be difficult to determine in a large city such as Bangalore where much exposure takes place via broadly accessible media such as television, billboards, and primary school programs. It was judged more appropriate to use a population-level variable that was known to vary with exposure to low-fertility cultural norms rather than an individual-level variable, the interpretation of which would have been less clear. Thus, using aggregate data seems a reasonable way to test the cultural transmission models, but it does not substitute for additional tests with individual-level data.

The findings in context

The findings presented in this paper are consistent with those of many nonevolutionary studies on the demographic transition (for a good overview, see Caldwell et al., 2006). Most notably, the finding that a woman's education is one of the best predictors of her fertility is widely discussed in the demographic literature on the fertility transition in the developing world (e.g., Becker et al., 1990; Mason, 1997; Robinson, 1997). The most detailed work on the relationship between development and investment motivations in the region has been done in India's neighbor, Bangladesh. John Caldwell and collaborators have published a series of articles demonstrating how microeconomic factors have changed the payoffs for investing in children through the devaluation of children's work and the increasing utility of education in obtaining high-paying jobs (Caldwell et al., 1999, Caldwell and Khuda, 2000). Another type of investment research comes from Kabeer (2001) who suggests that Bangladesh's exploding population has put pressure on arable land and created a motive for parents to reduce the number of heirs. These findings highlight the relevance of investment-related approaches, which emphasize how the changing ecology in modern developing economies makes investing more in a smaller number of children a strategic, or even a necessary, choice. In keeping with this, previous work with the Bangalore data has suggested that parental investment motivations linked to economic development are the primary impetus behind increasing expenditures on children's education and marriage costs (Shenk, 2004, 2005), and that high levels of investment may have positive ramifications over more than one generation (Shenk, 2007).

Nonevolutionary approaches to cultural transmission, referred to as diffusion models in this literature, have also received a significant amount of attention in South Asia. For example, studies have found diffusion effects for contraceptive use rates (Arends-Kuenning, 2001), changes in ideal family size (Cleland et al., 1994; Kincaid, 2000), and changes in women's roles and other cultural values (Basu, 1993; Basu and Amin, 2000; Namboodiri, 1994) in India and Bangladesh. Though this literature lacks a theory of ultimate causation provided by an evolutionary perspective, these findings underline the potential relevance of cultural transmission in bringing about fertility transition and highlight the fact that there may be numerous proximate attitudes or norms that can be changed.

Risk-related models have not been widely addressed in the literature on the region, and those treatments that do exist (e.g., Chandrasekhar, 1972; Chaudhry, 1982; Cleland et al., 1994) are often not detailed nor do they present consistent results. Chandrasekhar (1972) and Cleland et al. (1994), among many other authors, discuss the fact that mortality has an inverse relationship with fertility and is expected to retard fertility decline, but they do not test this hypothesis in a detailed fashion. Chaudhry (1982), however, finds that mortality decline begins well before fertility decline in his all-India sample and concludes that it is therefore unlikely to be a strong predictor of the demographic transition.

Studies that explicitly compare the efficacy of different explanatory models are rare in the demographic literature. One exception is a study by Sanderson and Dubrow (2000), which compared three models of fertility decline across numerous societies and found that, though infant mortality was the best predictor, female empowerment (similar to investment-related models) was also important. Several papers on the region do, however, address multiple causes. For example, Caldwell et al. (1984) did a nine-village survey in Karnataka State (for which Bangalore is the capital), which investigated the causes of an ongoing demographic transition. They found that fertility reduction was related to the decline in infant mortality, nontraditional messages being taught by schools and cinema, and children becoming more expensive due to education and dowries. These results support our results in that they identify multiple significant causal factors, including those we have discussed. They are also the most realistic comparison because the locations are quite close geographically and culturally.

SUMMARY AND CONCLUSIONS

This paper has shown evidence for significant decreases in fertility in South India over the course of the 20th century. It has also shown an accompanying increase in the age of marriage and, by implication, the age at first reproduction. These analyses indicate that smaller number of surviving children per woman are related to increased investment in mothers and their children (measured here by formal education), improved risk profiles for children (represented by decreasing infant mortality rates), and increased cultural transmission of low-fertility norms and behaviors (represented by the number of fertility clinics and related low-fertility propaganda campaigns). Given the temporal depth of the sample, it is likely that these motivations were key contributions to the demographic transition that occurred in 20th century Bangalore. The evidence indicates that motivations related to educational investment are stronger than risk motivations or cultural transmission motivations in predicting low fertility, which suggests that investment motivations may have been more important in fertility decline over time. Increased age at marriage is also linked to all three types of motivations, though increasing educational investment appears to be the best predictor, again suggesting that it may be the best predictor of the temporal trend toward later marriage. Finally, an investigation of the sequence of events during the demographic transition in Bangalore suggests that investment models are correct in predicting that economic changes preceded fertility decline while the availability of contraception followed it. It also appears, contrary to the predictions of some risk models, that decreased fertility preceded mortality declines in Bangalore.

Several tentative conclusions can be drawn from this paper. First, the importance of variables relating to investment, risk, and cultural transmission as correlates of reduced fertility in Bangalore suggests that such explanations are not mutually exclusive and that thorough studies of the demographic transition should take all three models into account. Second, the similarity of the results for both number of surviving children and bride's age at marriage implies that similar social forces are likely to be causing both demographic patterns. Third, several types of evidence suggest that investment-related motivations may have been the primary or initial driver of the demographic transition in Bangalore, India. Finally, these findings suggest that age at first reproduction is only one proximate mechanism by which lower fertility is achieved. A direct effect of investment or other motivations on the number of children desired or produced is also probably important.

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