The Causal Relationship between Fertility and Infant Mortality: Prospective Analyses of a Population in Transition

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Abstract: This paper examines causal processes underlying change in demographic outcomes among the Tsimane of lowland Bolivia. Using prospective data collected between 2002 and 2010, we show that the loss of an infant leads to an earlier progression to the next birth, as do prospective measures of maternal health and energy balance. The total fertility rate is about 9.0, but greater integration with the Bolivian market and educational system is associated with lower fertility rates. The data indicate tangible trade-offs between fertility and infant mortality. Infants of first-time mothers who delay reproduction show significantly improved survival rates. For parous mothers, short interbirth intervals increase the mortality risks of subsequent infants. Infant mortality is also significantly predicted by indicators of the mother's nutritional and health status. We discuss these results in light of broader secular trends in demographic rates in South America as a whole.

Introduction

Understanding the relationship between fertility rates and infant and juvenile mortality risks has been a longstanding interest of demographers and biologists. Standard demographic transition theory is one classic approach (Coale 1973; Coale and Watkins 1987; Davis 1945; Davis 1963). This theory posits that mortality rates for infants and children drive fertility rates, mediated through cultural, social and psychological processes. Those social processes have the effect of keeping population size stable. Under conditions of high mortality, high fertility rates are required to keep populations from shrinking. When there is a transition from high to low mortality rates, cultural processes, albeit with some lag, will result in reduced fertility rates. After a period of rapid growth, the population returns to stable equilibrium.

Life history theory derived from evolutionary biology posits a bi-directional relationship between fertility and juvenile mortality risks (Blurton Jones 1986; Cole 1954; Kaplan 1996; Smith and Fretwell 1974). According to the theory, organisms face a trade-off between quantity and quality of offspring. Increasing fertility reduces available time and energy to invest in each individual offspring, increasing their likelihood of dying. At the same time, for organisms that engage in post-natal investment in offspring (including all birds and mammals), the death of an existing offspring releases time and energy for the mother to invest in new replacement offspring. The theory proposes that natural selection results in organisms possessing characteristics that will tend to maximize biological fitness, often measured by the number of surviving offspring they produce. According to the theory, the effect of an exogenous reduction in mortality risks to offspring will depend on how it affects the trade-off between quantity and quality of offspring. By increasing the number of existing offspring demands on the mother, reductions in mortality will tend to reduce fertility, but if the cause of reduced mortality is due to an increase in available resources, organisms may respond by increasing fertility, if that will increase their fitness. For most organisms, populations will eventually return to equilibrium due to resource constraints.

Many traditional native South Americans, living in the lowland areas of Amazonia, are currently undergoing transition in mortality rates. The demographic history of those groups reveals large swings in population size, due to the effects of contact with Europeans. During the first centuries of contact, there were large demographic collapses throughout the Americas, due to both introduced diseases and economic, social and political disruption {see (Livi Bacci 2007) for a review}. The rubber boom in the late 19^{th} century also caused further demographic disruptions. The effects of these disruptions were greater for settled groups than for nomadic small-scale societies, living in the interior of the forest and on small water courses. Many of those small-scale societies continued to live traditional lifestyles until the latter part of the 20^{th} century. As they make increasing contact with global forces (including, minimally, change in access to land and resources, education, public health), they are experiencing demographic change as well; in many cases, the result is rapid population growth.

The goal of this paper is to examine the causal processes underlying change in demographic outcomes in one traditional native South American society, the Tsimane of lowland Bolivia, with the goal of shedding light on the relationship between fertility and mortality. While the vast majority of Tsimane remain subsistence forager-farmers, people and communities vary in distance from the nearest town, in their ability to speak Spanish from none to fluent, their access to medical care, their educational level from none to high school, and in their degree of economic exchange with outsiders (Gurven et al. 2007). Using prospective data collected between 2002 and 2010, we first present descriptive data on age-specific fertility and total fertility rates and how they vary by distance from the town of San Borja. We then examine the determinants of parity progressions among parous women, using a proportional hazards approach. Next, a comparable analysis is given, regarding the transition to first birth. The second section of results examines the determinants of mortality risks for infants, first for higher-order births and then for first-born children. Finally, we compare secular change in mortality and fertility rates among the Tsimane, using historical demographic data, to Bolivia as a whole.

Methods

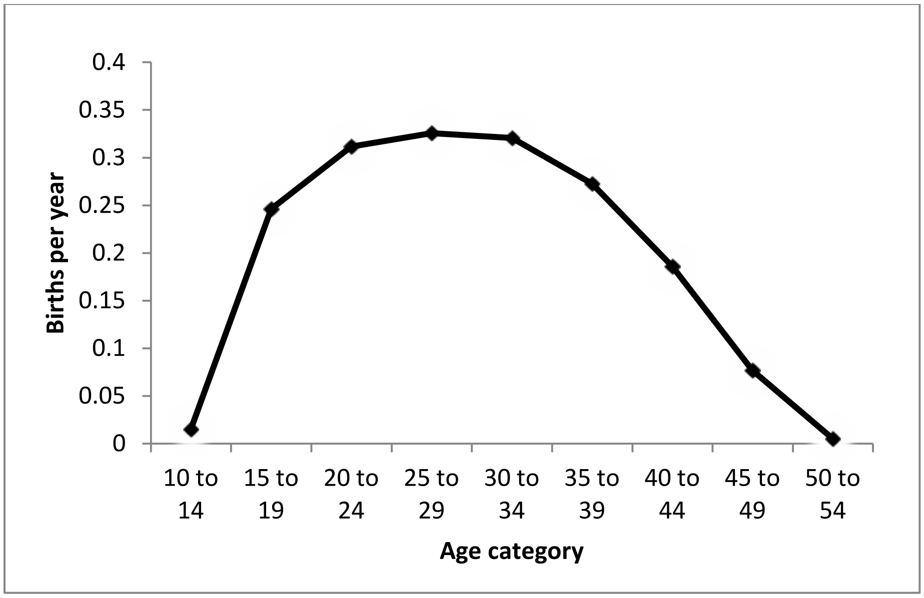
Longitudinal data on health status, fertility, and mortality were collected in 26 Tsimane villages from 2002 to 2010 under the aegis of the Tsimane Health and Life History Project. Census data were maintained throughout this period documenting the age, sex, community membership, and parents of each individual born or living in the sample villages. Retrospective reproductive histories were collected from a subset of adults in this sample according to methods described in Gurven et al. (2007). Yearly medical exams and interviews were conducted by a mobile team of Bolivian physicians and biochemists. These exams recorded height, weight, pregnancy status, and parity. White blood cell count was quantified by biochemists using a microscope or portable hematology analysis machine. Spanish speaking ability and completed years of education were also recorded.

The subsequent analyses of age at first birth and parity progressions draw on the census data collected during the sample period (2002-2010), supplemented by retrospective demographic interview data where available. Cox proportional hazard models were estimated predicting age at first birth, and time to next birth following a birth that occurred during or immediately preceding the sample period. Logistic regression models were estimated predicting the likelihood of each child born dying within one year of birth. Total fertility and infant mortality rates before 2002 were drawn exclusively from demographic interview data. Nation-wide Bolivian demographic data were obtained from the UN Common Database, UNICEF.

Results

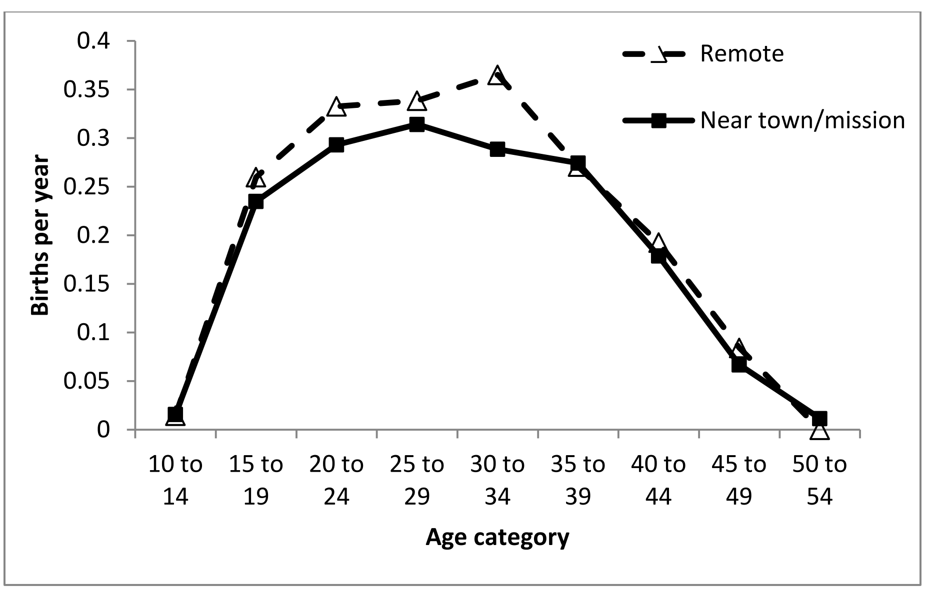
The total fertility rate (TFR) for the entire sample of Tsimane from 2002 to 2010, based on 5730 risk years for births, is 8.8. Figure 1 shows the age-specific fertility rates from which the TFR is derived.

Figure 1. Age-specific fertility rate among Tsimane women



There is some evidence of regional variation in age-specific fertility. If we divide the population into the more remote Tsimane villages and those that are either near the town of San Borja or at a large mission settlement, fertility rates are somewhat higher for women in more remote communities during peak reproductive years (Figure 2), resulting in TFRs of 9.3 and 8.4, for remote and near villages, respectively.

Figure 2. Regional variation in age-specific fertility rate among Tsimane women



Parity Progressions

Table 1 shows the results of a Cox proportional hazards analysis of 1,157 risk intervals for the progression from one birth to the next birth among parous women (650 intervals terminated with a birth and 507 were censored). It shows that a) women who speak Spanish well have significantly lower rates of progression to next birth than do women who speak some or no Spanish (see Figure 3a for the corresponding functions); b) women with Body Mass Indexes (BMI) less than 20.5 (one standard deviation below the mean) also have lower progression rates (Figure 3b); c) the death of the infant whose birth began the interval increases the progression to the next birth (Figure 3c); and d) rates of progression decrease with age of woman, radically after age 35 (Figure 3d).

Table 1. Cox proportional hazards analysis of the probability of giving birth among parous women

Variable	B	SE	*p*	Exp(B)
Spanish fluency				
High	-0.416	0.127	0.001	0.659
Moderate	0.023	0.086	0.79	1.023
None (baseline)	0	---	---	1
Body Mass Index				
Low (< 20.5)	-0.257	0.122	0.036	0.773
Normal (≥ 20.5) (baseline)	0	---	---	1
Survival of previous infant				
Dies before age 1	0.559	0.183	0.002	1.748
Survives to age 1 (baseline)	0	---	---	1
Age category				
45-49	-1.697	0.363	<0.001	0.183
40-44	-1.995	0.205	<0.001	0.136
35-39	-0.894	0.131	<0.001	0.409
30-34	-0.283	0.113	0.012	0.753
25-29	-0.165	0.102	0.106	0.848
20-24 (baseline)	0	---	---	1

Figure 3a

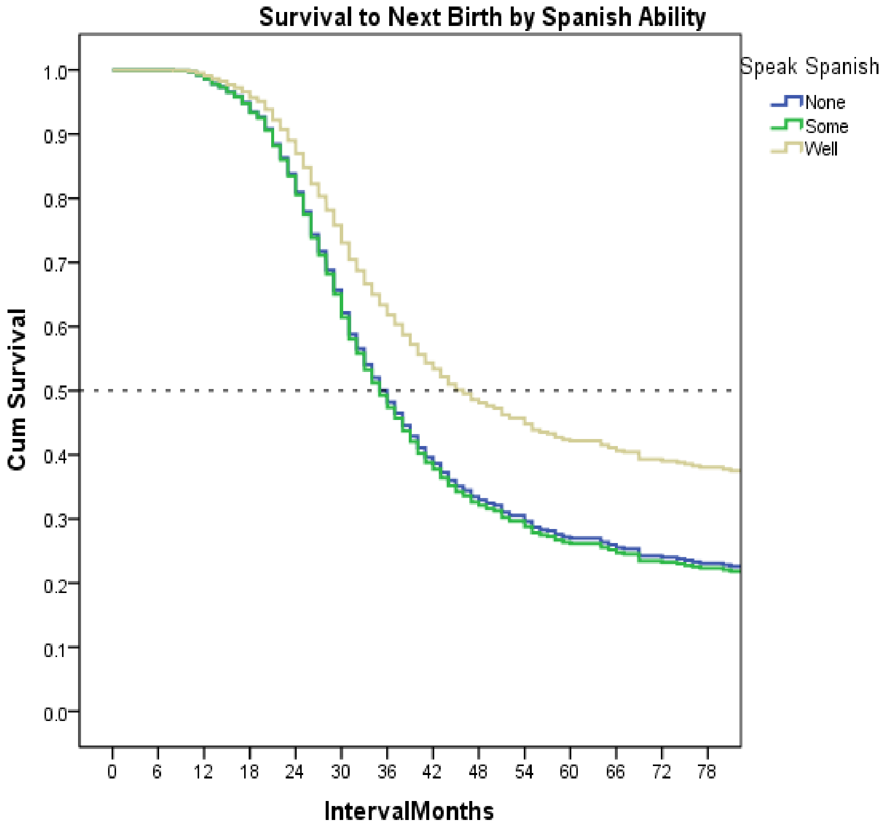


Figure 3b

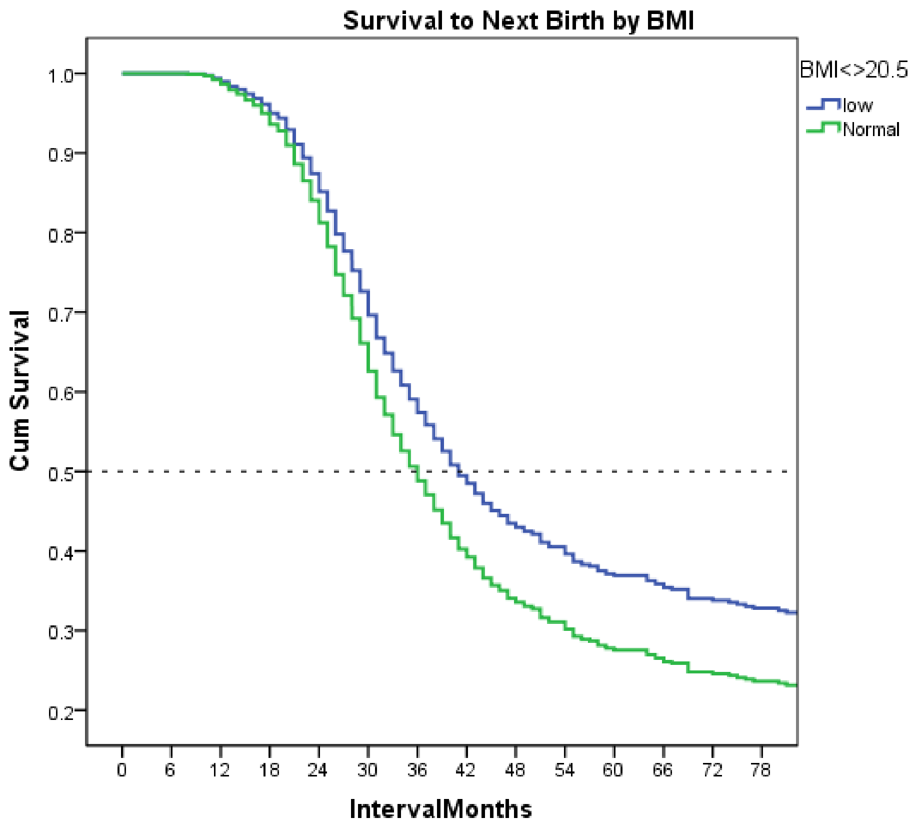

Survival to Next Birth by BMI
BMI<>20.5
low
Normal
Cum Survival
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
6
12
18
24
30
36
42
48
54
60
66
72
78
IntervalMonths

Figure 3c

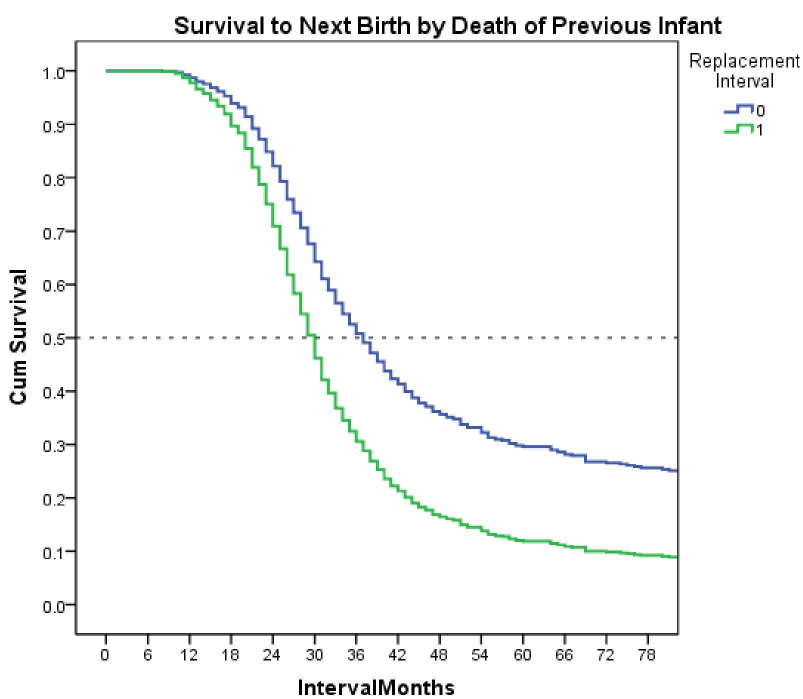
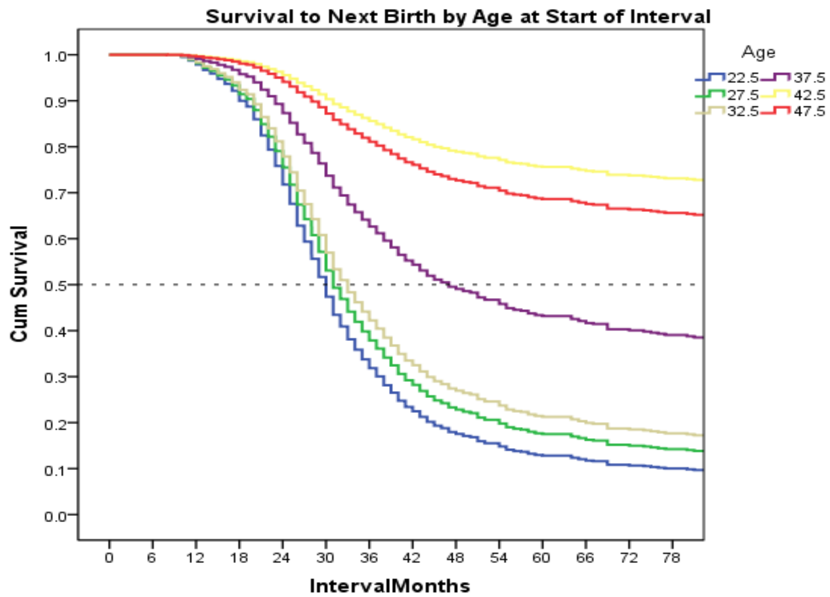

Survival to Next Birth by Death of Previous Infant
Replacement Interval
0
1
Cum Survival
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
6
12
18
24
30
36
42
48
54
60
66
72
78
IntervalMonths

Figure 3d



Progression to First Birth for Nulliparous Women

Table 2 shows a Cox proportional hazards analysis of the predictors of first birth. It shows that a) there is a general trend to earlier first births over time; b) education has a large effect on the transition to first birth (although the direction of causality may be unclear) – those with 0 or 1 year of education transition first, those with 2 or 3 years of education transition later, and those with four or more years of education transition last (Figure 4a); c) there are regional differences in fertility with those near town transitioning later (Figure 4b) and d) BMI higher than the average of 18.1 is associated with faster transition to first birth (Figure 4c).

Table 2. Cox proportional hazards analysis of the probability of first birth

Variable	B	SE	*p*	Exp(B)
Year born	0.14	0.069	0.042	1.15
Education				
Low (≤ 1 year)	0.396	0.166	0.017	1.486
Medium (2 – 3 years) (baseline)	0	---	---	1
High (≥ 4 years)	-0.469	0.166	0.005	0.626
Region				
Near town/mission	-0.302	0.126	0.017	0.74
Remote (baseline)	0	---	---	1
Body Mass Index				
Above mean	0.278	0.12	0.021	1.321
Below/at mean (baseline)	0	---	---	1

Figure 4a

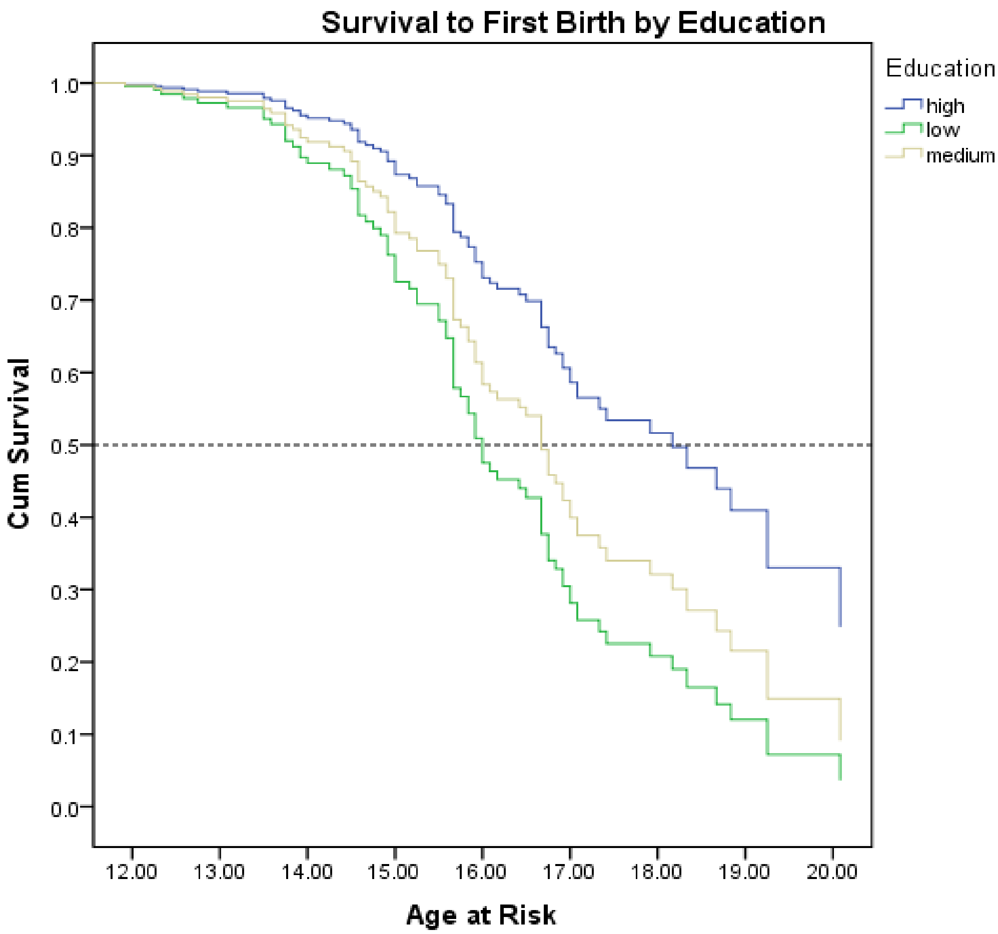


Figure 4b

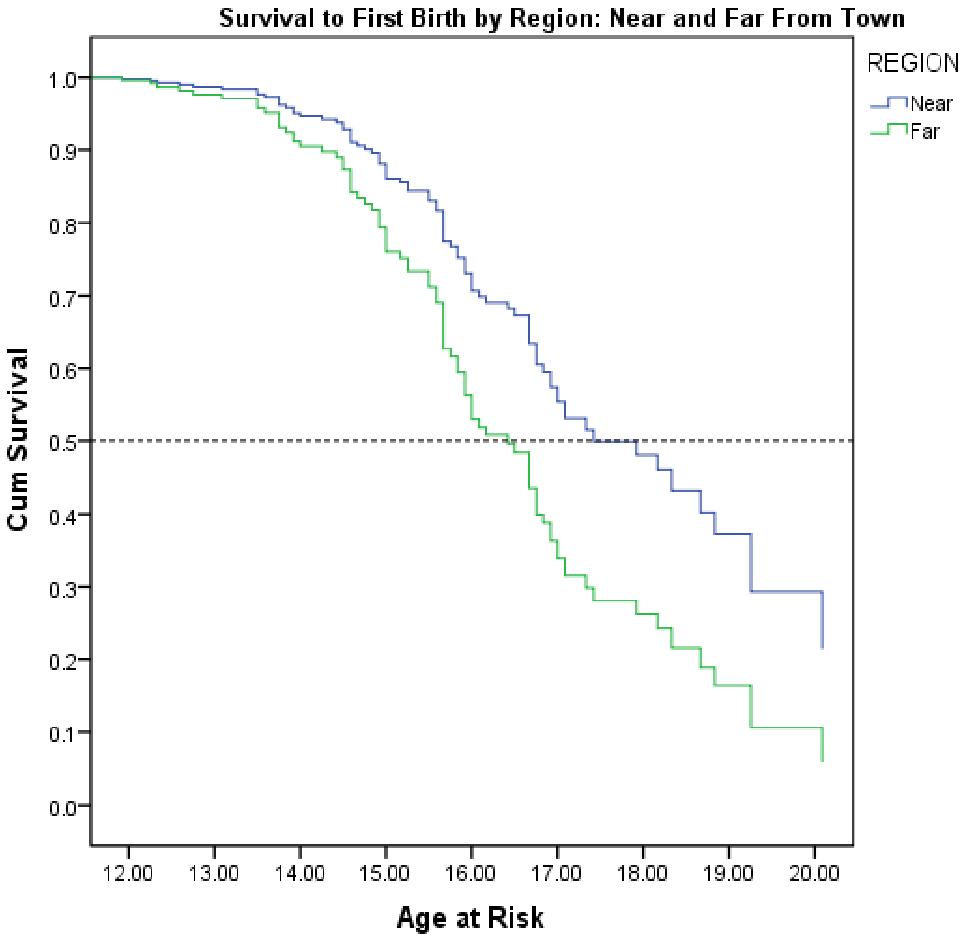
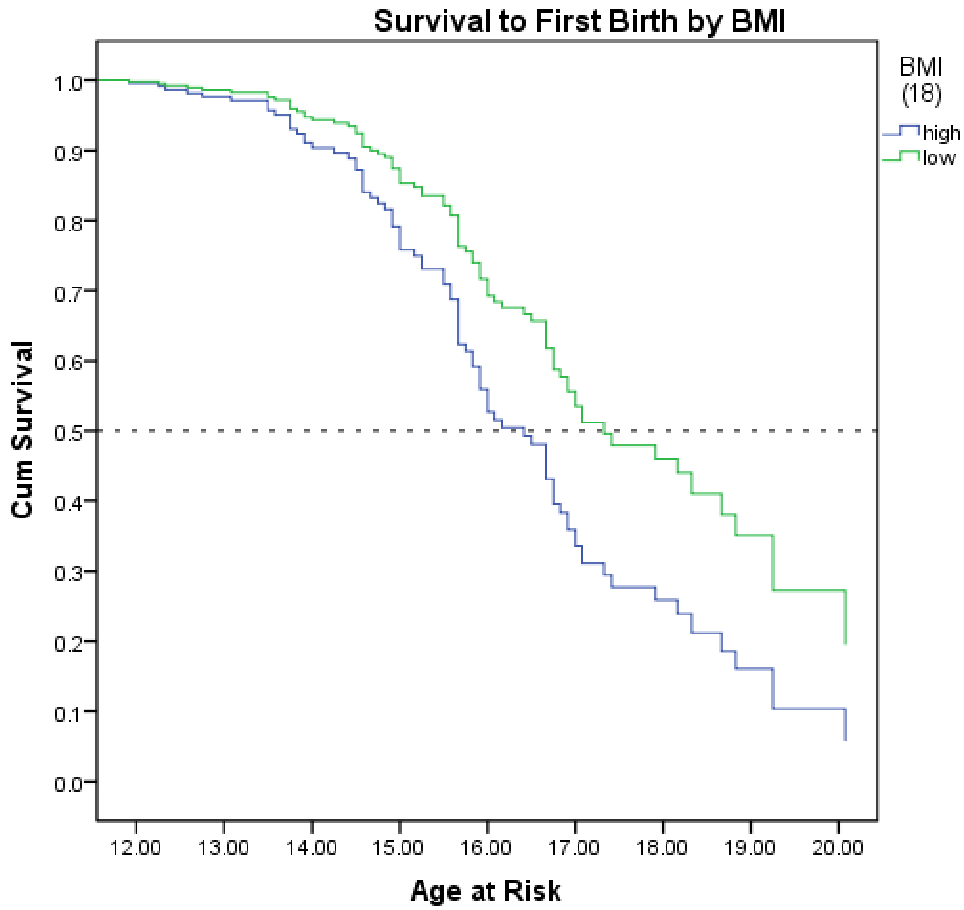

Survival to First Birth by Region: Near and Far From Town
REGION
Near
Far
Cum Survival
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
12.00
13.00
14.00
15.00
16.00
17.00
18.00
19.00
20.00
Age at Risk

Figure 4c



Infant Mortality Rates: Higher-Order Births

Table 3 presents analysis of the predictors of infant mortality in the first year of life, using Generalized Linear Models in SPSS with a logistic link function (N=857 births of which 32 or 3.7% died in the first year of life). It shows that a) mother's BMI negatively predicts infant death with the odds ratio decreasing by 86.4 percent for each additional unit of BMI; b) there is a strong interaction of previous birth interval and region in determining mortality – short intervals of less than 2 years increase mortality hazards by more than four-fold in remote regions with no access to medical treatment, but do not affect mortality rates in regions with access (see Figure 5a); c) children born to mothers over age 35 have about twice the mortality risk of children born to younger mothers (figure 5b); d) there are dramatic changes to mortality risks over time, with rates dropping by close to 23% per year over the course of the study period and e) neither maternal education or the ability to speak Spanish were significantly related to mortality rates (results not shown).

Table 3. Predictors of infant mortality in the first year of life

Variable	B	SE	*p*	Exp(B)
Maternal BMI	-0.146	0.069	0.033	0.864
Region*Length of prior birth interval				
Remote*Short (<2 years)	1.55	0.449	0.001	4.713
Near town/mission*Short	0.217	0.477	0.648	1.243
Remote*Longer(≥2 years)	0.212	0.537	0.693	1.236
Near town/mission*Longer (baseline)	0	---	---	1
Maternal age at birth				
>35	0.752	0.386	0.05	2.121
≤35 (baseline)	0	---	---	1
Year of study	-0.25	0.092	0.006	0.779

Mortality Risks for First Born Infants

First born children die at almost twice the rate of later born children (7% vs 3.7%). Table 4 shows the predictors of mortality for 207 first born children. It shows that a) there are strong regional difference in mortality, with first-borns in remote regions almost 4 times as likely to die as their counterparts in regions with access to medical care; b) the infants of mothers with high white blood cell counts are more likely to die, with an odds-ratio of 1.17 for each additional 1000 cells per cubic millimeter of blood; c) mothers age at birth has a very strong affect on mortality risks, for each additional year of mother's age, with an odds ratio of .68; d) a counter-intuitive impact of maternal body weight (unlike older mothers) where heavier mothers have higher infant mortality rates, but an intuitive effect of height where taller mothers have lower infant mortality rates and e) neither maternal education or the ability to speak Spanish were significantly related to mortality rates (results not shown).

Table 4. Predictors of mortality for 1st born children

Variable	B	SE	*p*	Exp(B)
Region				
Remote	1.382	0.64	0.031	3.984
Near town/mission (baseline)	0	---	---	1
Maternal white blood cell count (x $10^3/mm^3$)	0.161	0.081	0.045	1.175
Maternal age at birth	-0.382	0.179	0.032	0.683
Maternal body weight (kg)	0.173	0.062	0.006	1.189
Maternal height (cm)	-0.134	0.07	0.056	0.875

Figure 6. Infant mortality rates of Tsimane and Bolivia by year

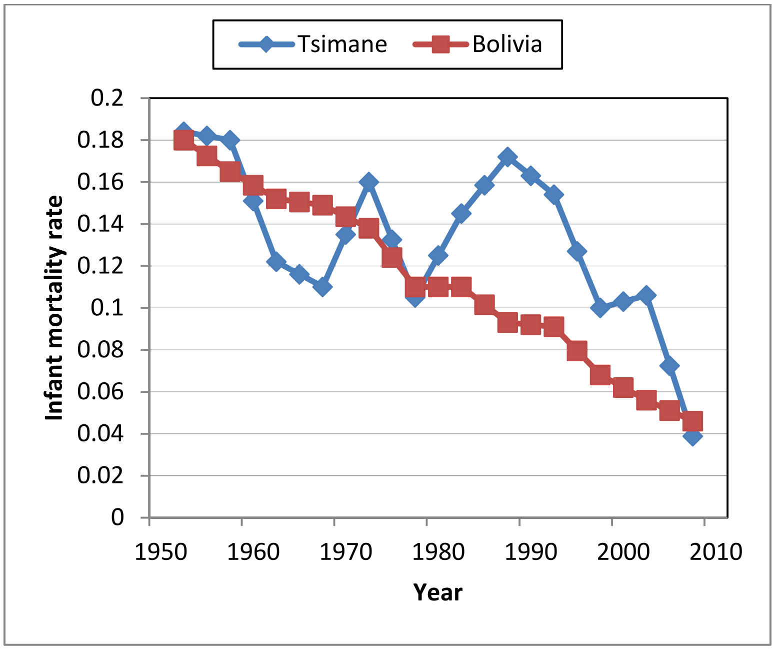
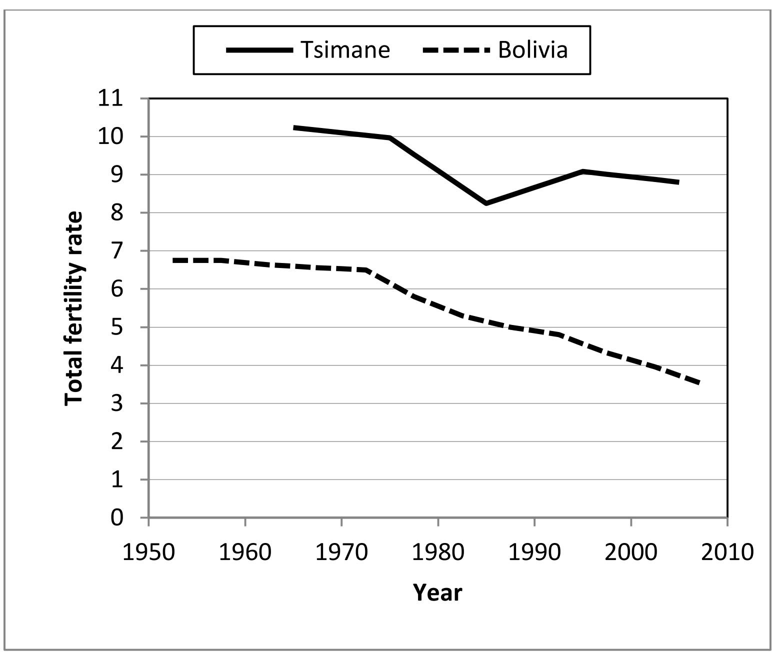


Figure 7. Total fertility rates of Tsimane and Bolivia by year



Changes in Fertility and Infant Mortality over Time: Tsimane and Bolivia Compared

Figures 6 and 7 shows a comparison between the mortality and fertility rates of the Tsimane and the rest of Bolivia, using historical demographic data. There is remarkable similar in the trajectory of mortality rates, but the fertility rate changes are very dissimilar. By 2009, we find that the infant mortality rate has dropped to about 4% for the Tsimane and for Bolivia as a whole. However, from 1975 to 2009, total fertility rates dropped by 46% from 6.6 to 3.5 in Bolivia as a whole, but there has been very little change in the Tsimane TFR over time.

Discussion

These results provide considerable evidence of a bi-directional relationship between fertility and mortality. For parous mothers, the loss of an infant does lead to earlier progression to the next birth. In remote areas with very reduced access to medical services, a short interval between births increases the mortality risk to the subsequent infant by about four fold. Age of first birth has also has a dramatic effect on infant mortality rates, reducing the mortality risk by close to a third for each additional year that a young women delays reproduction. With respect to production of surviving offspring, there is a trade-off between fertility (both its initiation and its resumption following a birth) and infant mortality.

Physiological energy stores appear to play an important role in determining both fertility and mortality. Body Mass Index predicts the rate of transition to first birth and parity progressions for parous women. Maternal BMI, measured prior to the birth of the infant, also predicts infant mortality for higher-order births. For first births, the results were more complicated, since maternal height predicts reduced mortality but maternal weight predicts higher mortality. This counter-intuitive results requires further investigation. Since girls are still increasing in body mass during their teens when first births generally occur, some young mothers may be sequestering more resources for themselves at a cost to the baby. In any case, the prospective research design provided evidence of the role of selection bias or phenotypic correlation in the determinants of both fertility and mortality.

Secular change in fertility rates is much weaker than in mortality rates. About 10% of the parous women in our sample speak Spanish well. Their rates of transition to next birth were lower than for women who speak little or some Spanish. Presumably, increasing numbers of women will speak Spanish as time progresses. For the transition to first birth, there are two opposing trends. Over the course of the study, progression rates to first birth increased by about 15% per year (i.e. decreasing average age of first birth). At the same time, however, controlling for other factors, there is also evidence that young women with more education (>4 years) initiate reproduction later. In some cases, however, pregnancy may have terminated schooling rather than vice versa.

Mortality, on the other hand, has been decreasing rapidly over time. In the multivariate analyses, there is no evidence that maternal education or ability to speak Spanish affects infant mortality rates. Given the strong regional effects on mortality, it appears that much of the secular trend in mortality rates is due to increased access to western medical treatment, especially antibiotics and rehydration therapy. One remote area that is served by a medical post with itinerant teams visiting the villages had similar infant mortality rates to villages near the town of San Borja, where there is a hospital.

Whereas secular change in mortality rates among the Tsimane are keeping pace with the rest of Bolivia, there is a dramatic difference in rates of change for fertility. Overall, there has been little or no change in total fertility rates over time among the Tsimane, whereas TFRs have dropped from 6.6 to 3.6 for Bolivia as a whole. It is clear that understanding the relationship between mortality and fertility over historical time requires a more in-depth analysis of other mediating factors.

References Cited

Blurton Jones NB. 1986. Bushman birth spacing: a test for optimal interbirth intervals. Ethology and Sociobiology 4:145-147.

Coale AJ. 1973. The demographic transition. IUSSP Liege International Population Conference Liege: IUSSP 1:53-72.

Coale AJ, and Watkins SC, editors. 1987. The Decline of Fertility in Europe. Princeton, N.J.: Princeton University Press.

Cole LC. 1954. The population consequences of life history phenomena. Quarterly Review of Biology 29:103-137.

Davis K. 1945. The World Demographic Transition. Annals of the American Academy of Political and Social Science 237:1-11.

Davis K. 1963. The theory of change and response in modern demographic history. Population Index 29:345-366.

Gurven M, Kaplan H, and Zelada Supa A. 2007. Mortality Experience of Tsimane Amerindians of Bolivia: Regional variation and temporal trends. American Journal of Human Biology 19:376-398.

Kaplan HS. 1996. A theory of fertility and parental investment in traditional and modern human societies. Yearbook of physical anthropology 39:91-135.

Livi Bacci M. 2007. Conquest: The Destruction of the American Indios. Cambridge, UK: Polity Press.

Smith CC, and Fretwell SD. 1974. The optimal balance between size and number of offspring. American Naturalist 108:499-506.