Hum Nat
DOI 10.1007/s12110-010-9092-2

Examining the Relationship between Life Expectancy, Reproduction, and Educational Attainment

A Cross-Country Analysis

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Abstract Life history theory aims to explain the relationship between life events, recognizing that the fertility and growth schedules of organisms are dependent on environmental conditions and an organism's ability to extract resources from its environment. Using models from life history theory, we predict life expectancy to be positively correlated with educational investments and negatively correlated with adolescent reproduction and total fertility rates. Analyses of UN data from 193 countries support these predictions and demonstrate that, although variation is evident across world regions, strong interactions exist among life expectancy, reproductive investments, and educational attainment, and these relationships occur independently of economic pressures and disease burdens. The interactions are strongest, however, in countries with a life expectancy of ≥60 years as these countries tend to have stable economies and a limited HIV/AIDS burden. These findings suggest that policies aimed at influencing education and reproductive decisions should consider environmental characteristics that drive people's expectations about their longevity.

Keywords Demographic factors · Educational status · Fertility · Life cycle · Mortality · Reproductive behaviors

According to the World Health Organization's World Health Report (2008), people are healthier, wealthier, and living longer today than 30 years ago. The average global life expectancy at birth is estimated to increase by 7 years from 1998 to 2025, with 26 countries having a life expectancy at birth above 80 years. Increases in global life expectancy are attributed to improvements in sanitation and access to clean water; medical advances, including childhood vaccines; and massive increases

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Published online: 12 October 2010

in agricultural production as a result of the Green Revolution. Rapid population growth resulting from decreased mortality began in 1950. However, the global population growth rate has decreased by almost half since reaching its peak of 2.2% in 1965–1970 (United Nations 1999) as a result of many countries going through demographic transitions characterized by increasing education and declining fertility. In this article we examine how changes in life expectancy influence the timing and extent of reproduction and investments in education.

Life history theory recognizes that the timing of life events (birth, adolescence, reproductive onset, reproductive termination, and death) is dependent on environmental conditions and an organism's ability to extract resources from its environment (Roff 2002; Stearns 1992). Natural selection is assumed to have designed organisms to balance the inherent trade-offs between investments in reproduction and growth (often considered as trade-offs between current and future reproduction). Fluctuating environmental conditions that increase extrinsic mortality favor increased reproductive effort and short-lived organisms (i.e., little investment in somatic maintenance; Schaffer 1974). When the risks of mortality are high, organisms are expected to reproduce *frequently,* to increase the probability of some offspring surviving to maturity, and *early,* to ensure reproduction before death (Koons et al. 2008). However, in stable environments with low risks of extrinsic mortality, selection can favor delays in reproduction to invest in somatic growth, which not only impacts survivorship but also increases an organism's ability to extract resources from the environment. When competition for resources is high in stable environments, selection favors greater parental investment and a reduced number of offspring (Promislow and Harvey 1990; Stearns 1992; Wilson 1975).

Life history theory is concerned with investments in physical growth, but organisms—especially humans—also make significant ontogenetic investments in knowledge and skills (Hill and Kaplan 1999; Kaplan et al. 2009). These educational investments can be analyzed as part of the basic life history trade-offs between growth and reproduction (Eisenberg 1981; Gould 1977; Hill and Hurtado 1996; Kaplan et al. 2000; Kaplan and Lancaster 2003; Lerner 1984). Investments in education delay reproduction but increase future income as well as survivorship, a relationship that has been observed worldwide (Schultz 1993). For example, in Brazil, increasing years of education were found to correlate with incremental decreases in total fertility and increases in wages (Lam and Duryea 1999). In a Thai population experiencing declining fertility rates, Knodel et al. (1990) found that children from smaller families were more likely to continue education to higher levels.

However, if extrinsic mortality or future unpredictability is high, delays in reproduction will not be favored, nor will investments in education whose benefits cannot be realized until later in the lifespan. Various studies have found that adolescents who anticipate having a shorter lifespan reproduce at an earlier age than adolescents who expect to have a longer lifespan (Brumbach et al. 2009; Geronimus 1996a, b, 2001, 2004; Hill et al. 1997; Wilson and Daly 1997). In addition, in the United States between 1980 and 2001, Meara et al. found "very little change in life expectancy among less-educated black and white non-Hispanics and very substantial increases in life expectancy among the more educated" (2008:356). Similar relationships between education and life expectancy have been observed elsewhere, including Brazil

(Camargos et al. 2007), Finland, Sweden, Norway, Denmark (Silventoinen and Lahelma 2002; Valkonen et al. 1997) and Europe (Mackenbach et al. 1997).

In this paper we build on Low et al.'s (2008) life history analysis of cross-cultural patterns of female reproduction. Their analysis of more than 170 nations reveals a strong relationship between life expectancy and age at first birth; however, they found a threshold life expectancy at 60 years that affects the relationship between life expectancy and age at first birth across countries. Life expectancy and age at first birth are positively correlated in countries in which life expectancy at birth is ≥60 years, but for countries with life expectancies shorter than 60 years, no clear relationship exists. The authors attribute the lack of a relationship in countries with life expectancies less than 60 years to potential states of non-equilibrium resulting from volatile socio-ecological conditions.

Life expectancy at birth is a demographic indicator describing, as defined by the United Nations Human Development Report, "the number of years a newborn infant would live if prevailing patterns of age-specific mortality rates at the time of birth were to stay the same throughout the child's life" (2007:368). Low et al. (2008) analyze the relationship between life expectancy and reproduction by stratifying country-level data into development status using a composite indicator—the Human Development Index (HDI). First calculated in 1990, HDI serves as a frame of reference for both social and economic development. HDI measures the average achievements of a country in a single statistic by combining indicators of health, knowledge, and standard of living. Health is measured by life expectancy at birth; knowledge is measured by a combination of the adult literacy rate (%) and the combined gross primary, secondary, and tertiary school enrolment ratios; and standard of living is measured by Gross Domestic Product per capita (Purchasing Power Parity US$).

Analyses of the relationships among life expectancy, reproduction, and education relying on stratifications by HDI are unable to take into account the composite indicator's direct relationship with life expectancy and education. In addition, analyses cannot control for, or isolate the effects of, economic development, as these are included in the composite HDI value. Low et al. conclude: "If we can isolate particular components that strongly affect life expectancy and AFB [women's age at first birth], we [will] have a clearer idea of what relatively easily influenced variables might be the focus of policy interventions to increase life expectancy and AFB" (2008:215).

This paper aims to take on that challenge by isolating the component measures of HDI—life expectancy at birth, adult literacy rate, gross enrolment in school, and GDP—to examine the interaction among life expectancy, reproduction, and education. The relationships between life expectancy, reproductive behavior, and educational investments consist of a feedback loop in which improvements in education are expected to increase life expectancies and favor declines in reproduction, which further increases investments in education (Hill and Kaplan 1999). The causal links among life expectancy, reproduction, and educational investments are dependent on the stage of the demographic transition a population is experiencing. Countries vary in the rates at which they pass through stages in the demographic transition. Some countries, such as China, Brazil, and Thailand, have moved through the stages of demographic transition rapidly as a result of economic and social changes; other countries, particularly in

Africa, have stalled owing to economic stagnation and the impact of AIDS. Therefore, when examining the relationships among life expectancy, reproduction, and education it is important to control for economic factors (e.g., Dorling et al. 2006; Lamptey et al. 2006; Preston 1975; Rodgers 1979; Sen 1993) and disease indicators (e.g., Anderson 2010; Quinlan 2007). Indeed, these factors may account for the lack of any correlation between life expectancy and age at first birth among populations with low life expectancy (<60 years) as observed by Low et al. (2008).

Here, building on Low et al.'s (2008) results and recommendations, we examine the components of the HDI that affect life expectancy across societies in three steps: (1) correlating life expectancy with variables for reproduction and education, and factors known to influence life expectancy, such as GDP and HIV/AIDS deaths; (2) determining if a threshold life expectancy exists for measures of reproduction and education used in our analyses, consistent with the findings of Low et al. (2008); and (3) controlling for the influence of covariates and regional variation on the relationships among life expectancy, reproduction, and education, and determining if differences in the relationships exist between counties with high and low life expectancy. Based on the above discussion, we predict life expectancy to be negatively correlated with adolescent reproductive rate and total fertility and positively correlated with educational investments, whilst controlling for covariates and regional variation, and that these relationships may not exist in countries with low life expectancy.

Methods

We acquired the data used in our analyses from specialized agencies of the United Nations system, including health (World Health Organization, WHO), education (United Nations Education Scientific and Cultural Organization, UNESCO), economics (World Bank), and life expectancy (World Population Prospects). National datasets must be regarded with some level of caution as data gaps and issues of inconsistency and incoherence remain owing to differences in the effectiveness of infrastructure, political agendas, and additional factors, such as internal conflicts. However, the UN agencies rely on an extensive peer review process conducted through leading regional and national statistical offices as well as international organizations to ensure the highest level of data consistency and accuracy. For this analysis we used data from 2006. Missing data were replaced with 2005 data when available.

Our analysis includes all components of the HDI: life expectancy; adult literacy rate; primary, secondary, tertiary, and combined gross school enrolment ratios; and GDP. School enrolment ratios are the numbers of students enroled in primary (elementary and middle school), secondary (high school), and tertiary (college or university) levels of education, regardless of age, expressed as a percentage of the population of theoretical age corresponding with those levels (United Nations 2007). Gross Domestic Product (PPP US$) (GDP) is the sum of the net output of all producers in an economy, plus product taxes not included in the valuation of output, converted to US dollars, and accounting for price differences across countries such that one US dollar has the same purchasing power in the domestic economy as it does in the United States (United Nations 2007).

In addition to the variables used in the calculation of the composite HDI index, our analyses examine adolescent birth rate and total female fertility. Adolescent birth rate is defined as the annual number of births to women aged 15–19 years per 1,000 women in that age group (WHO 2009). Total female fertility is defined as the number of children that would be born to each woman if she were to live to the end of her childbearing years and bear children at each age in accordance with age-specific fertility rates in the region and in a given year (United Nations 2007). Our analyses also include a disease indicator—deaths from HIV/AIDS, defined as the estimated number of adults and children that have died because of HIV/AIDS in a specific year, expressed per 100,000 population (WHO 2009).

Bivariate correlations (Pearson's *r*) were conducted to identify relationships among life expectancy, reproduction, educational investment, and covariates. Correlation analyses do not require the grouping of variables or imply causal directionality. Given the evidence of existing variation in women's education, marriage, and fertility prospects across nations (Low 2005), the 193 nation-states used in this analysis were categorized into eight UNESCO world regions to further isolate indicators that may have greater impact in some regions relative to others (see Tables 1 and 7 for world regions). Variations between countries within the UNESCO regional categories likely exist; however, these regions do offer some categorization of countries by level of development, ethnicity, religion, culture, and disease burden. In addition, we did not weight data by the relative population size of each country because relationships in countries with large populations would override those in countries with smaller populations, thus negating the impact of sociocultural factors.

To analyze both trends and potential thresholds in the relationships between life expectancy and investments in reproduction or education, we divided countries into five groups based on life expectancy and calculated median values for indicators of reproduction (adolescent birth rate and total female fertility) and education (adult literacy rate and primary, secondary, tertiary, and combined gross school enrolment ratios). Median values were compared across life expectancy stratifications to identify threshold life expectancies.

Finally, we used multivariate regression analysis to control for factors known to impact life expectancy (GDP and HIV/AIDS deaths) and regional differences (dummy variables). We elected this method rather than using adjusted life expectancy estimates that exclude deaths from HIV/AIDS so as to observe the impact of both economic and disease indicators independently. We also conducted separate multivariate regression analyses for countries with life expectancies above and below 60 years to determine if the potential thresholds hold when controlling for covariates. All analyses were conducted using SAS version 9.2 for Windows (SAS Institute, Cary, NC, 2002).

Results

Table 1 shows the bivariate correlations among life expectancies, indicators for reproduction, educational attainment, and possible covariates. Increases in life expectancy correspond to significant decreases in adolescent birth rate and total female fertility. All variables measuring educational attainment, excluding primary

Table 1 Pearson's correlations between life expectancy and indices for reproduction, education, GDP, and HIV/AIDS by world region

		World region							
	Overall life expectancy (*n*)	Arab States (*n*)	Central Asia (*n*)	Central & Eastern Europe (*n*)	East Asia & the Pacific (*n*)	Latin America & the Caribbean	Northern America & Western Europe (*n*)	Southwest Asia (*n*)	Sub-Saharan Africa (*n*)
Female fertility									
Adolescent birth rate	−.705*** (181)	−.505** (19)	.691** (9)	−.469** (21)	−.596*** (25)	−.192 (31)	−.381* (23)	−.750** (9)	−.278* (44)
Total female fertility	−.805*** (188)	−.674*** (20)	−.725** (9)	.021 (21)	−.660 (29)	−.605*** (32)	.114 (23)	−.953*** (9)	−.435*** (45)
Education									
Adult literacy rate (%)	.699*** (186)	.680*** (20)	.191 (9)	−.057 (21)	.783*** (23)	.502*** (35)	.267 (25)	.820*** (9)	.136 (44)
Overall school enrolment ratio	.753*** (190)	.800*** (20)	−.170 (9)	−.137 (21)	.686*** (28)	.488***(35)	−.271 (24)	.520 (9)	.324** (44)
Primary school enrolment ratio	.103 (182)	.644*** (20)	−.299 (8)	.313 (20)	.196 (25)	−.031 (34)	−.349* (24)	.124 (9)	−.062 (42)
Secondary school enrolment ratio	.810*** (174)	.893*** (20)	−.164 (8)	.217 (19)	.743*** (24)	.142 (34)	−.127 (24)	.706** (9)	.464*** (36)
Tertiary school enrolment ratio	.676*** (145)	.604** (16)	−.043 (8)	−.269 (19)	.673** (23)	.392* (24)	−.128 (23)	.634* (7)	.337* (33)
Covariates									
Gross Domestic Product (GDP)	.595*** (193)	.556*** (20)	.046 (9)	.389* (21)	.776*** (29)	.396** (35)	−.035 (25)	.611* (9)	.226 (45)
HIV/AIDS deaths per 100,000 population	−.613*** (182)	−.737*** (20)	.938*** (9)	−.293 (21)	−.487** (25)	−.269 (31)	.044 (23)	−.262 (9)	−.556*** (44)

*$p<0.10$, **$p<0.05$, ***$p<0.01$

school enrolment, were highly correlated with overall life expectancy, suggesting that there are corresponding increases in life expectancy and investment in education.

The lack of an association between life expectancy and gross primary school enrolment (r=0.103, p=0.166) may be a result of overall high enrolment rates, and therefore a lack of variation both globally and locally relative to secondary and tertiary school enrolment [mean (SD): 102.4 (15.1), 75.5 (28.6), and 31.66 (26.4), respectively]. These findings also may suggest that a threshold level of education is necessary for improvements in life expectancy beyond a certain number of years (Lam and Duryea 1999) or, conversely, that a threshold life expectancy is needed for educational attainment beyond a certain level.

We examined correlations between GDP and life expectancy at the global and regional levels. Consistent with other research (Dorling et al. 2006; Lamptey et al. 2006; Preston 1975; Rodgers 1979; Sen 1993) we found significant bivariate correlations between life expectancy and GDP on a global scale (Table 1). However, there was considerable variation in this relationship by region, with three of the eight regions exhibiting no significant relationship between standard of living (GDP) and life expectancy (Table 1).

Examination of the impact of disease, using HIV/AIDS deaths per 100,000 population, found a significant, negative correlation with life expectancy. As one would expect, increases in HIV/AIDS deaths correspond to declines in life expectancy. Regional differences exist as countries with high HIV/AIDS prevalence experience a drop in life expectancy (Lamptey et al. 2006). Variations in the relationship between life expectancy and HIV/AIDS may be a result of the rapid and dramatic influence HIV/AIDS has had on life expectancy in certain countries (Low et al. 2008). Dramatic shifts in life expectancy over relatively short periods of time may confound the relationship between life expectancy and reproduction. However, Gant et al. (2009) found that not all countries with a heavy HIV/AIDS burden have experienced drastic declines in life expectancy. As these authors recognize, "[s]adly, for many people in Sub-Saharan Africa, AIDS is just another way of dying" (2009:43).

Table 2 displays the median adolescent birth rate, total female fertility, adult literacy rate, and school enrolment ratios when countries are separated into five strata of life expectancy. As anticipated, these data show decreasing trends in adolescent birth rates and total female fertility and increasing trends in the education measures (with the exception of gross primary school enrolment ratio) as life expectancy increases. Median gross primary school enrolment ratios remain fairly stable across life expectancy strata, consistent with correlations in Table 1. Figure 1a shows the variation, but also consistent negative trends, across regions when total female fertility is plotted against life expectancy. Figure 1b shows the positive relationship between adult literacy rates and life expectancy in regions where there is sufficient variation in adult literacy rates across countries to detect such a trend.

Trends in reproduction and education variables, however, are not linear. Table 2 shows that the greatest differences (approximately twofold) in median reproduction rates (adolescent birth rate and total female fertility) occurred between the second (51.0–61.2 years) and third (61.3–71.2 years) life expectancy strata, indicating the same clear threshold at approximately 60 years that Low et al. (2008) found for age at first birth. The greatest differences in median adult literacy rate and overall, secondary, and tertiary enrolment ratios also occurred between the second and third life expectancy strata, ranging from approximately 1.5-fold to a fourfold increase.

Table 2 Summary statistics for indicators of education and reproduction by five life expectancy groups

Variable	Life expectancy				
	40.2–50.0 years	51.0–61.2 years	61.3–71.2 years	71.3–75.2 years	75.3–82.4 years
	Median, SD (*n*)	Median, SD (*n*)	Median, SD (*n*)	Median, SD (*n*)	Median, SD (*n*)
Adolescent birth rate	136.00, 59.49 (24)	105.50, 53.18 (24)	47.00, 33.02 (43)	30.00, 32.12 (42)	14.00, 23.58 (48)
Total female fertility	5.55, 1.34 (24)	4.83, 1.25 (24)	2.55, 1.05 (47)	2.20, 0.82 (44)	1.75, .49 (49)
Adult literacy rate (%)	67.40, 18.35 (23)	60.95, 20.64 (24)	90.55, 17.81 (42)	92.40, 6.36 (46)	99.00, 4.64 (51)
Overall school enrolment ratio	52.50, 13.42 (23)	52.65, 13.30 (24)	71.90, 13.25 (47)	77.35, 7.52 (46)	89.00, 11.56 (50)
Primary school enrolment ratio	105.40, 20.76 (21)	93.87, 27.79 (22)	102.41, 11.06 (46)	103.40, 10.78 (44)	102.10, 6.97 (49)
Secondary school enrolment ratio	30.37, 22.35 (17)	34.90, 14.01 (19)	80.76, 23.60 (46)	87.12, 11.57 (44)	98.84, 13.06 (48)
Tertiary school enrolment ratio	3.55, 3.85 (16)	3.73, 3.38 (17)	15.41, 20.74 (33)	33.12, 18.53 (32)	56.16, 25.10 (47)

Correlations between life expectancy, adolescent birth rate, and total female fertility calculated for countries with a life expectancy of <60 years were not significant (adolescent birth rate: $r=-0.253$, $p=0.094$, $n=45$; total female fertility: $r=-0.241$, $p=0.112$, $n=45$). Further analyses reveal that countries with a life expectancy of ≥60 years show strong positive correlations between life expectancy and both adolescent birth rate and total female fertility (adolescent birth rate: $r=-0.511$, $p<0.001$, $n=136$; total female fertility: $r=-0.588$, $p<0.001$, $n=143$).

Correlations between life expectancy and education calculated for countries with a life expectancy of <60 years were not significant (primary: $r=-0.239$, $p=0.127$, $n=44$; secondary: $r=0.092$, $p=0.597$, $n=42$; tertiary: $r=0.145$, $p=0.421$, $n=35$; Fig. 2). In contrast, countries with a life expectancy of ≥60 years show strong positive correlations between life expectancy and secondary and tertiary school enrolment (primary: $r=-0.002$, $p=0.986$, $n=140$; secondary: $r=0.677$, $p<0.001$, $n=139$; tertiary: $r=0.519$, $p<0.001$, $n=112$; Fig. 2). These findings suggest either that high secondary school enrolment ratios are important for improvements in life expectancy beyond 60 years or that a life expectancy beyond 60 years is fundamental for education at or beyond the high school level. These relationships are examined further using regression analysis to control for covariates.

Given the variation that exists in the standard of living and disease burden indicators, additional analyses presented here examine the relationship among life expectancy, education, and reproduction controlling for GDP, HIV/AIDS deaths, and regional variation. Results obtained from multivariate linear regression analyses are shown in Tables 3, 4, 5, and 6.

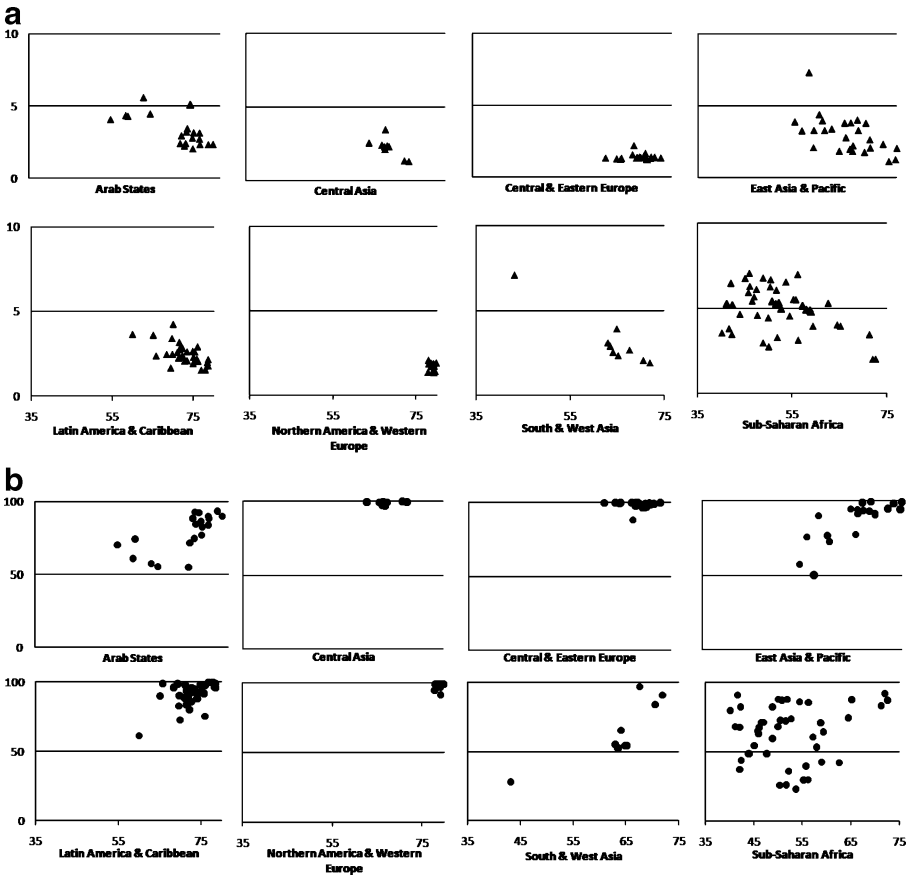

Fig. 1 Patterns of life expectancy, total female fertility, and adult literacy rate by world region: *x*-axis on all graphs is life expectancy (years) and *y*-axis is **a** total female fertility and **b** adult literacy rate (%)

All variables in our analyses are highly intercorrelated, so we initially examine them separately before including them in models with reproduction, education, and life expectancy. We also examine regional differences and provide models of two representative regions: northern America and western Europe, which hold the highest life expectancy estimates, and sub-Saharan Africa, which includes countries with the lowest life expectancy estimates. For relevant models, we will indicate regions that are similar to our two sample regions but will not present all of the regression models here (they are available upon request). Finally, to identify differences based on threshold values, we present models separately for countries with life expectancies above and below 60 years of age.

Tables 3 and 4 reveal significant associations between variables measuring reproduction (adolescent birth rate and total female fertility) and life expectancy. The relationships remain highly significant when GDP, HIV/AIDS deaths, and dummy variables for both regions are added to the models. Although multivariate models that include life expectancy suggest a negative relationship between HIV/AIDS

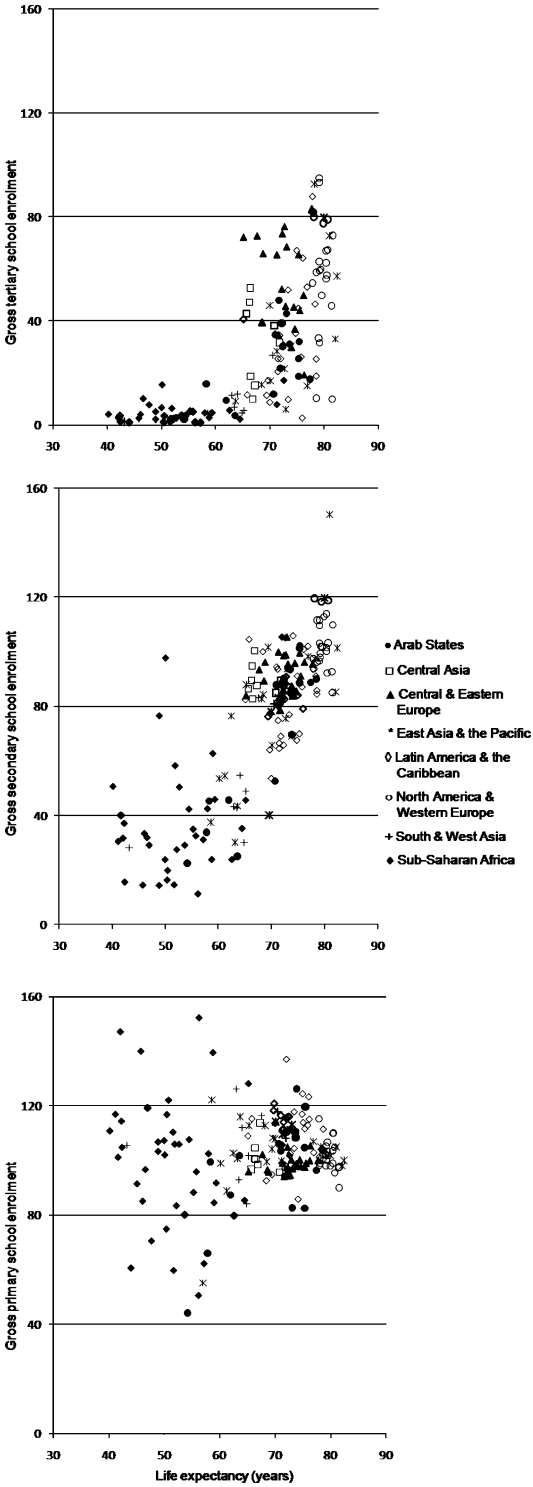

Fig. 2 Patterns of life expectancy and gross primary, secondary, and tertiary education enrolment ratios by world region

Table 3 Multivariate linear regression models showing the association of standardized regression coefficients for life expectancy and covariates (GDP and HIV/AIDS deaths per 100,000 people, dummy variables for the regions Northern America & Western Europe and Sub-Saharan Africa) with adolescent birth rate

	Adolescent birth rate			
Life expectancy	−.694***	−.775***	−.777***	−.489***
Gross Domestic Product (GDP)		−.078	−.091	−.138**
HIV/AIDS deaths per 100,000 people		−.206**	−.208***	−.233***
Northern America & Western Europe			.064	
Sub-Saharan Africa				.803***
Adjusted *r*-square (*n*)	.494 (181)	.524 (181)	.522 (181)	.565 (181)

$p<0.001$ for all models: *$p<0.10$, **$p<0.05$, ***$p<0.01$

deaths and variables measuring reproduction, bivariate correlations show that HIV/AIDS is positively correlated with both adolescent birth rate ($r=0.290$, $p<0.001$, $n=181$) and total fertility ($r=0.265$, $p<0.001$, $n=182$). The inclusion of a dummy variable for the northern America and western Europe region shows that variation in adolescent birth rate and total female fertility within this region is attributable to life expectancy and HIV/AIDS, with GDP having no significant impact on the relationship. This is also observed in East Asia and the Pacific, and in Latin America and the Caribbean for total female fertility only. However, the inclusion of a dummy variable for sub-Saharan Africa shows that other factors specific to this region account for variation in adolescent birth rate and total female fertility. This result is also observed in the Arab states, Central Asia, central and eastern Europe, Southwest Asia, and Latin America and the Caribbean for adolescent birth rate only. Factors that may account for regional variation include cultural values placed on childbearing and children, the need for children to work the land or in the household, religious values, women's access to the labor market, and lack of access to or utilization of contraception.

In Table 4, variables for education (adult literacy rate, overall and secondary school enrolment ratios) were added to the models. Education variables contribute significantly to the relationship between life expectancy and total female fertility. With the addition of regional dummy variables, we see that variation in total female fertility when controlling for adult literacy rate is attributable to region-specific factors in sub-Saharan Africa, central and eastern Europe, Latin America and the Caribbean, and Southwest Asia. Region-specific factors also account for variation in total female fertility when controlling for overall and secondary school enrolment ratios in sub-Saharan Africa, the Arab states, Central Asia, central and eastern Europe, and Southwest Asia.

Adult literacy rate and overall and secondary school enrolment ratios are all associated with life expectancy, even when controlling for GDP, HIV/AIDS, and the two regions (Table 5). Although multivariate models including life expectancy suggest a positive relationship between HIV/AIDS deaths and variables measuring education, bivariate correlations indicate that HIV/AIDS is negatively correlated with education variables (adult literacy rate: $r=-0.171$, $p=0.022$, $n=179$; overall enrolment: $r=-0.269$, $p<0.001$, $n=180$; secondary school enrolment: $r=-0.320$, $p<0.001$, $n=164$).

Table 4 Multivariate linear regression models showing the association of standardized regression coefficients for life expectancy, education, and covariates (GDP and HIV/AIDS deaths per 100,000 people, dummy variables for the regions Northern America & Western Europe and Sub-Saharan Africa) with total female fertility

	Total female fertility												
Life expectancy	−.803***	−1.081***	−.741***	−.915***	−.696***	−1.090***	−.853***	−.723***	−.588***	−.912***	−.727***	−.708***	−.574***
Gross Domestic Product (GDP)		.082	.074	.101*	−.281***	.035	.034	.043	.042	.044	.054	.081	.089*
HIV/AIDS deaths per 100,000 people		−.389***	−.226***	−.334***	.123**	−.392***	−.410***	−.231***	−.258***	−.344***	−.362***	−.285***	−.308***
Adult literacy rate (%)			−.383***					−.378***	−.345***				
Overall school enrolment ratio				−.107***						−.203***	−.162**		
Secondary school enrolment ratio					−.409***							−.404***	−.366***
Northern America & Western Europe						.235		.154		.296*		.195	
Sub-Saharan Africa							.644***		.459***		.600***		.473***
Adjusted *r*-square (*n*)	.646 (188)	.729 (182)	.787 (179)	.737 (180)	.750 (164)	.731 (182)	.754 (182)	.788 (179)	.800 (179)	.742 (180)	.760 (180)	.752 (164)	.764 (164)

$p<0.001$ for all models: *$p<0.10$, **$p<0.05$, ***$p<0.01$

Table 5 Multivariate linear regression models showing the association of standardized regression coefficients for life expectancy and covariates (GDP and HIV/AIDS deaths per 100,000 people, dummy variables for the regions Northern America & Western Europe and Sub-Saharan Africa) with adult literacy, and overall and secondary school enrolment ratios

	Adult literacy rate (%)			Overall school enrolment ratio				Secondary school enrolment ratio				
Life expectancy	.693***	.964***	.973***	.778***	.757***	.883***	.871***	.806***	.857***	.981***	.985***	.852***
Gross Domestic Product (GDP)		−.013	−.030	.024		.132**	.074	.148**		.113*	.130*	.136**
HIV/AIDS deaths per 100,000 people		.428***	.431***	.446***		.304***	.299***	.312***		.283***	.285***	.295***
Northern America & Western Europe			−.220				.291*				−.083	
Sub-Saharan Africa				−.531***				−.219				−.374**
Adjusted *r*-square (*n*)	.486 (186)	.586 (179)	.586 (179)	.602 (179)	.565 (190)	.655 (180)	.659 (180)	.656 (180)	.654 (174)	.730 (164)	.729 (164)	.737 (164)

$p<0.001$ for all models: *$p<0.10$, **$p<0.05$, ***$p<0.01$

Table 6 Multivariate linear regression models showing the association of standardized regression coefficients for life expectancy, education, and covariates (GDP and HIV/AIDS deaths per 100,000 people) with total female fertility separated by life expectancy thresholds (greater or less than 60 years of age)

	Total female fertility where life expectancy <60 years					Total female fertility where life expectancy ≥60 years						
Life expectancy	−.407**	−.947***	−.326*	−.994***	−.063	−.754***	−.356***	−.358***	−.561***	−.571***	−.428***	−.445***
Gross Domestic Product (GDP)		−.183		−.316		−.534		−.008		.020		.047
HIV/AIDS deaths per 100,000 people		−.347***		−.394***		−.306***		−.201		−.284		−.227
Adult literacy rate (%)	−.474***	−.183**					−.492***	−.490***				
Overall school enrolment ratio			−.496***	−.082					−.191**	−.206**		
Secondary school enrolment ratio					−.849***	−.355*					−.355***	−.383***
Adjusted *r*-square (*n*)	.416 (44)	.671 (44)	.259 (44)	.639 (44)	.472 (35)	.696 (35)	.501 (137)	.496 (135)	.372 (142)	.351 (136)	.436 (135)	.421 (129)

$p<0.001$ for all models: *$p<0.10$, **$p<0.05$, ***$p<0.01$

The inclusion of dummy variables for all regions shows that variation in indicators for education (adult literacy rate, overall and secondary school enrolment) is attributable to life expectancy and HIV/AIDS. However, the inclusion of a dummy variable for sub-Saharan Africa shows that in addition to life expectancy and HIV/AIDS, other factors specific to the region account for variation in adult literacy. This result is also observed in the Arab States, Central Asia, central and eastern Europe, and Southwest Asia. In addition, other, unknown factors account for variation in overall school enrolment in the Arab states and Central Asia, and for variation in secondary school enrolment in sub-Saharan Africa, Central Asia, and central and eastern Europe.

In models that include a dummy variable for the sub-Saharan Africa region, the relationships among reproduction, education, and life expectancy (excluding gross secondary school enrolment), HIV/AIDS deaths, and other unmeasured factors contribute significantly whilst GDP is only marginally important. (For further details on the influence of HIV/AIDS in the sub-Saharan Africa region, see Anderson 2010). In contrast, models containing a dummy variable for northern America and western Europe are representative of the combined data set, displaying the significant impact of life expectancy on the relationships but limited if any impact of GDP and/or other unmeasured factors.

Table 6 displays models where life expectancy, adult literacy, overall and secondary school enrolment ratios, and covariates are added as independent variables to determine the combined effect on total female fertility separately for countries with life expectancies below or above 60 years of age. For countries with life expectancies below 60 years, life expectancy in combination with HIV/AIDS is highly predictive of total female fertility. The education variables, overall and secondary school enrolment ratio, were significant in the models only when the impact of HIV/AIDS was not accounted for. This suggests that HIV/AIDS has a greater impact than education on the relationship between life expectancy and total female fertility in countries with lower life expectancies. In countries with life expectancy ≥60 years, variables for education remain significant even with the addition of GDP and HIV/AIDS, which were not significant in these models. These results support the findings in Table 2 that a threshold level of life expectancy may be necessary for changes in total female fertility and/or education.

Discussion

The results presented here support our hypotheses that life expectancy is associated with educational investments and the timing and extent of reproduction. Increases in life expectancy correspond to decreases in reproductive rate and total number of offspring, and increases in educational attainment. From this we surmise that when life expectancy is high, educational attainment is also high, reproductive timing is delayed, and overall reproduction reduced. As adolescent birth rate increases, adult literacy and the overall school enrolment ratio decrease ($r=-0.717$, $p<0.001$ and $r=-0.624$, $p<0.001$, respectively). The same strong inverse relationship exists between total female fertility and education (adult literacy: $r=-0.812$, $p<0.001$; overall school enrolment ratio: $r=-0.744$, $p<0.001$).

Variation in reproduction and education measures across regions suggests that although the relationship between short life expectancies and early and high fertility holds at multiple scales, differences exist at local levels (Wilson and Daly 1997; Geronimus 1996a, b, 1997, 2001). These variations may be the result of sociocultural differences, the influence of economic changes, or, as suggested by Low et al. (2008), the result of sudden changes in life expectancy (resulting from diseases, such as HIV, or warfare). In addition, stress created by a heavy disease burden or by conflict may also be a predictor of earlier age at menarche and at first birth (e.g., Chisholm et al. 2005). The multivariate models presented above show that when controlling for the influences of economic factors (GDP) and disease stressors (HIV/AIDS deaths), the relationships among life expectancy, reproduction, and education hold. GDP and HIV/AIDS explain variation in life expectancy in some regions (the Arab states, East Asia and the Pacific, and sub-Saharan Africa), but not all.

Uganda offers one example of the impact of disease on life expectancy and investments in education and reproduction. Uganda was one of 16 countries experiencing a decline in life expectancy between 1975 and 2000, mostly a result of high death rates from HIV/AIDS (it was ranked fifteenth of the 193 UN nation-states). In 2006, life expectancy was 27.5 years lower than that observed in the US; adolescent fertility rate was more than 250% higher than in the US, with only 24% of women using some form of contraception (2004 estimate, United Nations). However, the overall school enrolment ratio reached 62.3%, with 72.6% of the adult population being literate.

In contrast, Afghanistan has experienced no change in life expectancy but has experienced a persistent stressful environment owing to prolonged conflict. Indeed, Afghanistan's indicators for life expectancy, reproduction, and education are outliers compared with the other nine countries in the UNESCO's South and West Asia region (Table 7 and Fig. 1). Although social indicators were low even before the Soviet invasion in 1979, the prolonged conflict has left Afghanistan severely impoverished. Gross enrolment in education differs greatly by gender. The primary school enrolment ratio for males was 1.6 times greater than for females, and the secondary school enrolment ratio was 2.8 times greater. Half of the men and 85% of women are illiterate. Lack of proper housing, adequate schools, rural roads, communication, electricity, water, and sanitary conditions impedes improvements in health and contributes to low life expectancies.

Countries with high life expectancy generally experience greater political and economic stability, have greater economic success as measured by GDP, and are impacted less by diseases affecting adult survival, such as HIV/AIDS. Offspring success in such countries is dependent on acquired skills needed to compete economically, requiring considerable parental time and financial investment (Kaplan et al. 2000). As a result, more opportunities are available that reward educationally acquired skills and knowledge (Handwerker 1986). This compels a greater proportion of women to devote additional years to educational attainment, marry later, work before and after marriage, and increase their resource base (e.g., Low 2000a, b, 2005). As our data show, countries with higher life expectancies (≥60 years) have higher school enrolment ratios at every level of education, higher adult literacy rates, and lower adolescent birth rates and total female fertility. For these countries, relationships among indicators for education, reproduction, and life expectancy are significant.

In contrast, countries with low life expectancy have weaker government infrastructures and economies that are unable to respond to the needs of their populations, making them susceptible to civil warfare, natural disasters, and disease, and creating stressful environments. Although greater educational attainment improves health outcomes (Appiah and McMahon 2002), unstable environments support fewer opportunities that reward educationally acquired skills, thereby fostering low educational investments and early and frequent reproduction. As stated in the Human Development Report, "increased exposure to environmental stress is holding back the world's poor to build a better life for themselves and their children" (United Nations 2007:1). Our data show that in countries with a life expectancy below 60 years, school enrolment ratios and adult literacy rates are lower, and adolescent birth rates and total female fertility are higher than in countries with life expectancies above 60 years. However, in contrast to the latter countries, in countries where life expectancy is below 60 years relationships among education indicators, adolescent fertility rate, and life expectancy are not statistically significant.

Within-country variation undoubtedly exists that we cannot account for given the national-level data used. In addition, other factors influencing control over female fertility, including access to and acceptance and utilization of modern contraceptives, and religious and cultural beliefs, likely account for variation between and within countries. However, and consistent with other research, global and regional comparisons are highly suggestive of the predictive value of life expectancy on educational attainment (Camargos et al. 2007; Mackenbach et al. 1997; Meara et al. 2008; Silventoinen and Lahelma 2002; Valkonen et al. 1997) and reproduction (Chisholm et al. 2005; Low et al. 2008).

By isolating the component measures of HDI and using country-level data we have demonstrated that although cross-country variation exists, there are strong interactions among life expectancy, reproductive investments, and educational attainment, and these interactions occur independently of economic pressures and disease burdens. As argued by others (Caldwell 1980; Gant et al. 2009; Mamdani 1972; Maternowska 2006), our results suggest that increases in overall knowledge improve quality of life, access to resources and opportunities, and average life expectancy, and decrease and delay energy invested in reproduction. However, basic mass education at the primary level alone may not influence fertility transitions. As the feedback loop proposed by Hill and Kaplan (1999) suggests, changes in opportunity structure resulting from improvements in life expectancy and basic education further reward educationally acquired skills and perspectives, promoting secondary and tertiary education, which further increases life expectancy and lowers reproduction. Therefore, given their interactive effects, policies aimed at influencing education and reproductive decisions should consider environmental characteristics that drive people's expectations about their longevity.

Acknowledgments We thank Ruthanne Marcus, Merrill Singer, Katherine Hsu, Anna Layton, and Paul Swartwout for valuable comments on earlier drafts of this manuscript. A special thanks to Sowmya Rao for all her statistical guidance and continued support.

Appendix

Table 7 United Nations 193 nation-states included in the analyses by UNESCO world region

Arab States	Central Asia	Central & Eastern Europe	East Asia & the Pacific	Latin America & the Caribbean	Northern America & Western Europe	Southwest Asia	Sub-Saharan Africa
Algeria	Armenia	Albania	Australia	Antigua and Barbuda	Austria	Afghanistan	Angola, Benin
Bahrain	Azerbaijan	Belarus	Brunei Darussalam	Argentina	Belgium	Bangladesh	Botswana
Djibouti	Georgia	Bosnia & Herzegovina	Cambodia	Bahamas	Canada	Bhutan	Burkina Faso
Egypt	Kazakhstan	Bulgaria	China	Barbados	Cyprus	India	Burundi
Iraq	Kyrgyzstan Mongolia	Croatia	Fiji	Belize	Denmark	Iran	Cameroon
Jordan	Tajikistan	Czech Rep.	Hong Kong SAR	Bermuda	Finland	Maldives	Cape Verde
Kuwait	Turkmenistan	Estonia	Indonesia	Bolivia	France	Nepal	CAR, Chad
Lebanon	Uzbekistan	Hungary	Japan	Brazil	Germany	Pakistan	Comoros
Libya		Latvia	Kiribati	Chile	Greece	Sri Lanka	Congo
Mauritania		Lithuania Montenegro	Korea (North)	Colombia	Iceland		Côte d'Ivoire
Morocco		Poland	Korea (South)	Costa Rica	Ireland		DRC
Oman		Moldova	Laos	Cuba	Israel		Equatorial Guinea
Palestinian Autonomous Territories		Romania	Malaysia	Dominica	Italy		Eritrea, Ethiopia
Qatar		Russian Federation	Marshall Islands	Dominican Republic	Luxembourg		Gabon
Saudi Arabia Sudan		Serbia	Micronesia (Fed. States of)	Ecuador	Malta		Gambia
Syria		Slovakia	Myanmar	El Salvador	Monaco		Ghana
Tunisia		Slovenia	Nauru	Grenada	Netherlands Norway		Guinea
United Arab Emirates		Turkey	New Zealand	Guatemala	Portugal		Guinea-Bissau
Yemen		Ukraine	Palau	Guyana	Spain		Kenya

Yugoslav Rep. (former)	Papua New Guinea	Haiti	Sweden	Lesotho
	Philippines	Honduras	Switzerland	Liberia
	Samoa	Jamaica	United Kingdom	Madagascar
	Singapore	Mexico	United States	Malawi
	Solomon Islands	Netherlands Antilles		Mali
	Thailand	Nicaragua		Mauritius
	Timor-Leste	Panama		Mozambique
	Tonga	Paraguay		Namibia
	Vanuatu	Peru		Niger
	Viet Nam	St. Kitts & Nevis		Nigeria
		St. Lucia		Rwanda
		St. Vincent & the Grenadines		Sao Tome & Principe
		Suriname		Senegal
		Trinidad & Tobago		Seychelles
		Uruguay		Sierra Leone
		Venezuela		Somalia
				South Africa
				Swaziland
				Togo
				Uganda
				Tanzania
				Zambia
				Zimbabwe

References

Anderson, K. G. (2010). Life expectancy and the timing of life history events in developing countries. *Human Nature, 21*, 103–123.

Appiah, E. N., & McMahon, W. W. (2002). The social outcomes of education and feedbacks on growth in Africa. *Journal of Development Studies, 38*(4), 27–68.

Brumbach, B. H., Figueredo, A. J., & Ellis, B. J. (2009). Effects of harsh and unpredictable environments in adolescence on the development of life history strategies: a longitudinal test of an environmental model. *Human Nature, 20*, 204–268.

Caldwell, J. C. (1980). Mass education as a determinant of the timing of fertility decline. *Population and Development Review, 6*, 225–255.

Camargos, M. C., Machado, C. J., & do Nascimento Rodrigues, R. (2007). Disability life expectancy for the elderly, city of Sao Paulo, Brazil, 2000: gender and educational differences. *Journal of Biosocial Sciences, 39*(3), 455–463.

Chisholm, J. S., Quinlivan, J. A., Petersen, R. W., & Coall, D. A. (2005). Early stress predicts age at menarche and first birth, adult attachment, and expected lifespan. *Human Nature, 16*, 233–265.

Dorling, D., Shaw, M., & Smith, G. D. (2006). Global inequality of life expectancy due to AIDS. *British Medical Journal, 332*, 662–664.

Eisenberg, J. F. (1981). *The mammalian radiations*. Chicago: University of Chicago Press.

Gant, L., Heath, K. M., & Ejikeme, G. G. (2009). Early motherhood, high mortality, and rates of HIV/AIDS in sub-Saharan Africa. *Social Work in Public Health, 24*(1/2), 39–46.

Geronimus, A. T. (1996a). Black/White differences in the relationship of maternal age to birthweight: a population-based test of the weathering hypothesis. *Social Science & Medicine, 42*, 589–597.

Geronimus, A. T. (1996b). What teen mothers know. *Human Nature, 7*, 323–352.

Geronimus, A. T. (1997). Teenage childbearing and personal responsibility. *Political Science Quarterly, 112*, 405–430.

Geronimus, A. T. (2001). Inequalities in life expectancy, functional status, and active life expectancy across selected black and white populations in the United States. *Demography, 38*, 227–251.

Geronimus, A. T. (2004). Teenage childbearing as cultural prism. *British Medical Bulletin, 69*, 155–166.

Gould, S. J. (1977). *Ontogeny and phylogeny*. Cambridge: Harvard University Press.

Handwerker, W. P. (1986). The modern demographic transition: an analysis of subsistence choices and reproductive consequences. *American Anthropologist, 88*, 401–417.

Hill, K., & Hurtado, A. M. (1996). *Ache life history: The ecology and demography of a foraging people*. New York: Aldine de Gruyter.

Hill, K., & Kaplan, H. (1999). Life history traits in humans: theory and empirical studies. *Annual Review of Anthropology, 28*, 397–430.

Hill, E. M., Thomson, R. L., & Low, B. S. (1997). The role of future unpredictability in human risk-taking. *Human Nature, 8*, 287–325.

Kaplan, H. S., & Lancaster, J. B. (2003). An evolutionary and ecological analysis of human fertility, mating patterns, and parental investment. In K. W. Wachter & R. A. Bulatao (Eds.), *Offspring: Human fertility behavior in biodemographic perspective* (pp. 170–223). Washington: National Academies Press.

Kaplan, H., Hill, K., Lancaster, J., & Hurtado, A. M. (2000). A theory of human life history evolution: diet, intelligence, and longevity. *Evolutionary Anthropology, 9*, 156–185.

Kaplan, H., Hooper, P., & Gurven, M. (2009). The evolutionary and ecological roots of human social organization. *Philosophical Transactions of the Royal Society. Series B, Biological Sciences, 364*, 3289–3299.

Knodel, J., Havanon, N., & Sittitrai, W. (1990). Family size and the education of children in the context of rapid fertility decline. *Population and Development Review, 16*, 31–62.

Koons, D. N., Metcalf, C. J. E., & Taljapurkar, S. (2008). Evolution of delayed reproduction in uncertain environments: a life-history perspective. *The American Naturalist, 172*, 797–805.

Lam, D., & Duryea, S. (1999). Effects of schooling on fertility, labor supply, and investments in children, with evidence from Brazil. *The Journal of Human Resources, 34*(1), 160–192.

Lamptey, P. R., Johnson, J. L., & Khan, M. (2006). The global challenge of HIV and AIDS. *Population Bulletin, 61*, 3–24.

Lerner, R. (1984). *On human plasticity*. New York: Cambridge University Press.

Low, B. (2000a). Sex, wealth, and fertility—old rules, new environments. In L. Cronk, N. A. Chagnon, & W. G. Irons (Eds.), *Adaptation and human behavior: An anthropological perspective* (pp. 323–344). New York: Aldine de Gruyter.

Low, B. (2000b). *Why sex matters: A Darwinian look at human behavior*. Princeton: Princeton University Press.
Low, B. (2005). Women's lives there, here, then, now: a review of women's ecological and demographic constraints cross-culturally. *Evolution and Human Behavior, 26*, 64–87.
Low, B. S., Hazel, A., Parker, N., & Welch, K. B. (2008). Influences on women's reproductive lives: unexpected ecological underpinnings. *Cross-Cultural Research, 42*, 201–219.
Mackenbach, J. P., Kunst, A. E., Cavelaars, A. E., Groenhof, F., & Geurts, J. J. (1997). Socioeconomic inequalities in morbidity and mortality in western Europe. *The EU Working Group on Socioeconomic Inequalities in Health. Lancet, 349*, 1655–1659.
Mamdani, M. (1972). *The myth of population control: family, caste, and class in an Indian village*. New York: Monthly Review Press.
Maternowska, M. C. (2006). *Reproducing inequities: Poverty and the politics of population in Haiti*. Rutgers: Rutgers University Press.
Meara, E. R., Richards, S., & Cutler, D. M. (2008). The gap gets bigger: changes in mortality and life expectancy, by education, 1981–2000. *Health Affairs, 27*, 350–360.
Preston, S. (1975). The changing relation between mortality and level of economic development. *Population Studies, 29*, 231–248.
Promislow, D., & Harvey, P. (1990). Living fast and dying young: a comparative analysis of life-history variation among mammals. *Journal of the Zoological Society of London, 220*, 417–437.
Quinlan, R. J. (2007). Human parental effort and environmental risk. *Proceedings of the Royal Society. Series B, Biological Science, 274*, 121–125.
Rodgers, G. B. (1979). Income and inequality as determinants of mortality: an international cross-section analysis. *Population Studies, 33*, 343–51.
Roff, D. (2002). *Life history evolution*. Sunderland: Sinauer.
Schaffer, W. M. (1974). Optimal reproductive effort in fluctuating environments. *The American Naturalist, 108*, 783–790.
Schultz, T. P. (1993). Returns to women's education. In E. M. King & M. A. Hill (Eds.), *Women's education in developing countries: Barriers, benefits, and policies*. Baltimore: Johns Hopkins University Press.
Sen, A. (1993). The economics of life and death. *Scientific American, 266*, 40–47.
Silventoinen, K., & Lahelma, E. (2002). Health inequalities by education and age in four Nordic countries, 1986 and 1994. *Journal of Epidemiology and Community Health, 56*, 253–258.
Stearns, S. C. (1992). *The evolution of life histories*. Oxford: Oxford University Press.
United Nations (1999). Table 1: World population from year 0 to stabilization. *The world at six billion.* Available at http://www.un.org/esa/population/publications/sixbillion/sixbilpart1.pdf. Accessed October 17, 2009.
United Nations Development Programme. (2007). *Human development report 2007/2008. Fighting climate change: Solidarity in a divided world.* New York: Palgrave Macmillan. Retrieved from http://hdr.undp.org/en/media/HDR_20072008_EN_Complete.pdf. Accessed November 3, 2009.
Valkonen, T., Sihvonen, A. P., & Lahelma, E. (1997). Health expectancy by level of education in Finland. *Social Science & Medicine, 44*, 801–808.
Wilson, E. O. (1975). *Sociobiology: The new synthesis*. Cambridge: Harvard University Press.
Wilson, M., & Daly, M. (1997). Life expectancy, economic inequality, homicide, and reproductive timing in Chicago neighbourhoods. *British Medical Journal, 314*, 1271–1274.
World Health Organization. (2008). *World health report 2008: Primary health care now more than ever*. Geneva: WHO.
World Health Organization. (2009). *World health statistics: Indicator compendium,* unedited version. Geneva: WHO. Available at http://www.who.int/whosis/indicators/WHS09_IndicatorCompendium_20090701.pdf. Accessed November 16, 2009.

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