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Life Expectancy, Fertility, and Women's Lives: A Life-History Perspective

Bobbi S. Low[1,2], Nicholas Parker[1], Ashley Hazel[1], and Kathleen B. Welch[3]

Abstract

Women's reproductive lives vary considerably around the world, yet there are patterns to this variation. We explore reproductive patterns in 177 nations using the framework of human behavioral ecology. In humans, as in other species, there is a normally strong relationship between life expectancy at birth (e_0) and age at first birth (AFB). However, in studies of nonhuman species, this relationship is subject to two implicit assumptions: (a) that any population will be representative of the species, demonstrably untrue for humans (Low et al., 2008), and (b) that the relationship between e_0 and AFB is at equilibrium. What happens if, as is common in humans, changes occur rapidly in life expectancy? Here we explore the factors influencing how patterns of female life expectancy at birth (e_0) have changed since 1955. We examine the world's worst-off countries (in which e_0 did *not* predict AFB) to see what predicts life expectancy, age at first birth, and total fertility rate (TFR), and discuss how these features of human biocultural diversity may have policy implications for women's fertility and societal roles.

Keywords

life history, demography, comparative demography, life expectancy, equilibrium

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Introduction

Women's reproductive lives vary considerably around the world, yet there are patterns to this variation (Low, 2005a, 2005b). What drives the patterns? We explore, in an evolutionary framework that has proved explanatory in other species, reproductive patterns in 177 nations. We have found previously that human life-history patterns, while clearly culturally influenced, are also affected by largely hidden biological factors, just as are the life-history patterns of other species.

In particular, the biggest predictor of relative age at first birth (AFB) across species is life expectancy at birth (e_0; Harvey & Zammuto, 1985; see also Stearns, 1992, Figure 5.10). Behind this hypothesis lies the general principle that if all else were equal, earlier reproduction would always "win" in biological (fitness/lineage increase) terms over later reproduction, in growing populations (e.g., Fisher, 1958, modeled by Low et al., 2002). Of course, all is not equal; we can calculate an optimal age at first birth for any population. An important contribution to that calculation is age-specific mortality.

In studies of nonhuman species, this relationship is subject to two implicit assumptions: (a) that any population will be representative of the species (in contrast to most anthropological studies), and (b) that the relationship between e_0 and AFB is at equilibrium, that is, stationary and not changing over time. It will not surprise cross-cultural anthropologists that we found the first assumption was not met; there is considerable interpopulation variation in the human data (Low, Hazel, Parker, & Welch, 2008). AFB ranged from 18.2 to 29.6 years, and e_0 ranged from 31.3 to 82.2 years. It is not true that sampling any population will appropriately represent the species.

In this article we examine the second assumption. We explore how patterns of female life expectancy have changed since 1955 in human populations from around the world. We then look at the world's "worst-off" countries, referred to by the United Nations Development Programme (UNDP) as nations at "Human Development Level 3"; or "HDL-3." The people found in these countries approximate those termed the "Bottom Billion" by Collier (2007). For these nations, e_0 did *not* predict AFB. We examine them to see what best predicts life expectancy, age at first birth, and total fertility rate (TFR). In these countries, we would predict ecological, economic, and cultural constraints to be greatest because life expectancy at birth is shortest. Yet AFB varies independently of e_0 in these countries (Low et al., 2008).

Why a Life-History Framework?

We have argued (e.g., Low et al., 2008) that life-history theory may enrich anthropological studies, in part by providing a broad theoretical basis that generates testable predictions; and that in turn, cross-cultural studies, because they provide such rich comparative within-species data, may help refine life-history theory further. Life-history patterns—demographics—are shaped by the trade-offs all organisms face. Organisms invest time and energy into growth, maintenance, finding mates, raising offspring; but typically what is spent on one endeavor cannot be spent on another, and which expenditure is most effective at any moment depends in large part on environmental conditions (e.g., Roff, 1992, 2002; Stearns, 1992).

We use a life-history approach because it supplements as well as supports human demography (e.g., Anderson, 2010, Bock, 1999; Hill, 1993; Hill & Low, 1991; Kaplan, 1997; Kruger & Nesse, 2006; Low, 1993, 1998; Low et al., 1992, 2002; Mace, 2000; Robson & Kaplan, 2003). While standard demography and life-history theory often make similar predictions, there are areas in which life-history theory makes testable predictions where demography does not. For example, life-history theory predicts that life expectancy at birth will not only affect AFB but also that the lower the life expectancy, the higher will be age-specific fertility *at all ages*. This turns out to be true for humans, the only species we know to be tested (see Daly & Wilson, 1997; Hill et al., 1997; Low et al., 2008). Standard demography offers no predictive guidance in such cases as the relative remarriage rates of men versus women and the influence of (a) men's resources, (b) women's age (in life-history theory, women's age reflects reproductive value, or expected number of future children), and (c) existence of current children. Life-history theory offers explicit testable predictions: men will remarry more often than women and more often have second families in such unions; wealthier men will do so in greater proportions than poorer men; younger women, and childless women, will remarry more than older women with children. These predictions arise because of the relative reproductive importance in a mate market of resources for men, and reproductive value (Fisher, 1958) for women. For an overview, see Clarke and Low (2001). Thus we hope a life-history approach, combined with how much we know about cross-cultural ("within-species") variation, can help us understand the diversity we see in humans as well as feed back into hypothesis-testing in other species.

Materials and Method

UNDP Data

Most variables (see Table 1) are from the International Human Development Indicators' Database (http://hdr.undp.org/en/reports/global/hdr2005/). UNDP data are organized at the national level rather than the deeper ethnographic data we sometimes have for small-scale traditional societies (e.g., Hill & Hurtado, 1996). Thus patterns such as within-country variation in fertility patterns due to ethnicity or cultural norms that affect AFB or e_0 are typically obscured.

Some UNDP measures such as the proportion of births attended by medical professionals, doctors per 1,000 population, provision of clean water, and presence/absence of internal strife/civil war should have obvious connections to life expectancy. In these data, however, none showed as significant. Contributing to the variation, some countries have experienced recent shifts in life expectancy, suggesting the nonequilibrium conditions that are our focus here. Relationships among variables with $p \geq 0.20$ are not reported here.

The *Human Development Index (HDI)* is a compound variable from the UNDP that attempts to reflect health, education, and standard of living, using more than simple economic indicators. In this ranking, nations with stable infrastructure, good medical care, high average income per capita and widespread education tend to hold high ranks (in this sample, Norway ranks first; the United States eighth). In our data, we are conservative: rankings are clustered, following the UNDP categories, into "high" (HDI ranks = 1-63), "moderate" (64-146), and "low" (147-177) summary ranks. It can be highly misleading to use "exact" HDI rankings (Wolff et al., 2011). Furthermore, HDI rankings may change not only because the data change but also because of decisions by the UNDP to rank countries into three, or four, groups. For example, Bangladesh was ranked in HDI-3 (of three groups) in 2006 and in HDI-2 (of four groups) in 2010.

The *Gender Development Index (GDI)* measures achievement in the same basic capabilities as the HDI, but examines inequality in achievement between women and men. The GDI falls when the achievement levels of both women and men in a country are low *or* when the disparity between their achievements is high. The greater the gender disparity in basic capabilities, the lower a country's GDI compared with its HDI. Thus the GDI is simply the HDI discounted, or adjusted downwards, for gender inequality. This measure is important in the least well-off countries and, to some extent, in countries with religious

Table 1. Variables Used in the Analyses.

Variable	Abbrev	Source	Data from year(s)	Comments
Human development rank	HDI	UNDP	2005	1 = *high human development* 2 = *moderate development* 3 = *low development see text for further information*
Female life expectancy at birth	e_0	UNDP	1955, 1960, 1970, 1980, 1990, 2000, 2005	Derived from prevailing age-specific mortality schedules; national averages
Average age at first birth	AFB	UNDP	2005	National average; data may be missing in some worst-off countries with poor infrastructure
Total fertility rate	TFR	UNDP	2005	The children a woman would have if she lived her full reproductive years and, at each age, had the average number of children. Overestimates fertility in worst-off countries (ignores maternal and infant death).
Gender Development Index	GDI	UNDP	2005	Compares same capabilities as HDI, but compares M vs. F inequality in achievement. Low either with great sex disparity, or when both sexes score low
Gender ratio	GR	UNDP	2005	GR = GDI/HDI to reflect inequity more accurately than GDI. See HDP Technical Note 1, Low (2011).
Gender empowerment ratio	GEM	UNDP	2005	Composite variable assessing women's economic and political effectiveness.
Education gap	EG	World Economic Forum	2005	Female-to-male literacy rate, enrollment in primary, secondary, tertiary education
Dates for: genocide, independence, civil wars		CIA Factbook, August 2011	2010	Data also from D. Simon (personal Communication), Yale University.
HIV prevalence		CIA Factbook, August 2011	2010	

Note: Please see text for further information.

restrictions on women's behavior. Because the GDI can drop when both men and women have poor participation, it does not directly measure gender equity. One divides GDI/HDI to obtain what we call here the *Gender Ratio*, to reflect gender disparities more accurately (Low, 2011). We also use the *Gender Empowerment Measure* (GEM), which measures the extent to which women are able to participate in economic and political life, and take part in decision making. It measures something different from the *Gender Ratio* although the two measures are loosely correlated (*df*, 1, 68; $R^2 = .345$; $\beta = .587$).

Economic Forum Data

These come from the World Economic Forum 2007 report on gender differences (Hausmann, Tyson, & Zahidi, 2007). Data are from about 2005, and comparable to the UNDP measures. We use the measure *Education Gap*, which reflects the female to male ratio in literacy and enrollment in primary, secondary, and tertiary education, for examining some aspects of HDI-3 women's reproductive patterns.

Historical and Cultural Events

Historical descriptions (dates of genocide, HIV increases, timing of independence, civil war) are taken from *The World Factbook* (Central Intelligence Agency [CIA], 2010) with additional information from Africanist D. Simon (personal communication, November 23-26, 2011) of Yale University.

Statistical Treatment

We used SPSS 19 for general statistical analyses and model-building to examine gender inequities. Our multilevel modeling addresses some issues of Galton's problem about the relative independence of nearby cultures. We used SAS (9.2) Proc Traj for trajectory analyses (Jones & Nagin, 2007; Jones, Nagin, & Roeder, 2001), to identify common patterns of change in a variable over time. Designed specifically for such analyses, this procedure uses a discrete mixture model to identify groups of cases (here countries) that have similar time trajectories (here patterns of female life expectancies at birth over time), assuming that the trajectories follow a smooth polynomial function of time (linear, quadratic, or higher order). This procedure makes it possible to test whether equilibrium is a feasible conclusion within each identified group, by testing the linear, quadratic, and so forth, time components of the common trajectory of the group. This is a rather new development in time-series analysis, which in this case is preferable to a more standard multilevel model, in that a discrete mixture model can detect groups of countries based on their trajectories alone, without having to identify a priori groupings, thus allowing patterns that might not otherwise be discernible to be studied and the common characteristics of the countries with common trajectories to be examined.

Our trajectory analysis best-fit model selection is based on the change in the BIC (Bayesian Information Criterion) between models, as an approximation to the log of the Bayes factor (D'Unger, Land, McCall, & Nagin, 1998). The null hypothesis is that the minimum number of patterns (one) is the best model. When more complex models improve the BIC sufficiently, we continue to examine patterns. Twice the difference between the Bayesian Information Criterion of the best model and next-best model ($2 \times \Delta BIC$) is used to choose the best model; that is, the model with the most appropriate number of groups in the analysis. The strength of evidence against H_0 is minimal ("not worth mentioning") if $0 < (2 \times \Delta BIC) < 2$; positive evidence exists for an alternative model if $2 < (2 \times \Delta BIC) < 6$; such evidence is strong if $\Delta BIC\ 6 < (2 \times \Delta BIC) < 10$, and is very strong if $(2 \times \Delta BIC) > 10$ (Jones et al., 2001). The Appendix identifies the countries in each pattern grouping.

Results

Life Expectancy at Birth in HDI-1 and HDI-2 Countries

In the world's best-off countries for which we have full data ($n = 60$), SAS identified two strongly different trajectories in women's e_0 (Figure 1a; $2 \times \Delta BIC = 313.44$). In one group (HDI1-1), life expectancy in 1955 ranged from just less than 40 to just more than 60 for all countries except Oman ($e_0 = 38.3$ in 1955). Oman is the most dramatically changing country, beginning from e_0 of less than 40 in 1955. Most increases were steady, leveling off in 2000; Panama showed a slight decrease from 1990. The second pattern, identified for HDI-2 countries, began with a higher life expectancy in 1955. By 2005, both groups had similar levels of female life expectancy.

For the 81 countries analyzed in the HDI-2 group (Figure 1b), four different patterns were discerned ($2 \times \Delta BIC = 22.1$; still exceptionally strong). In trajectories HDI2-1, HDI2-2, and HDI2-3, female life expectancy improved until 2000, then continued to increase (HDI2-1), leveled off, or declined slightly (HDI2-2 and HDI2-3). Trajectory HDI2-1 contains two countries with dramatic decreases in life expectancy in 1980: Cambodia (Khmer Rouge) and

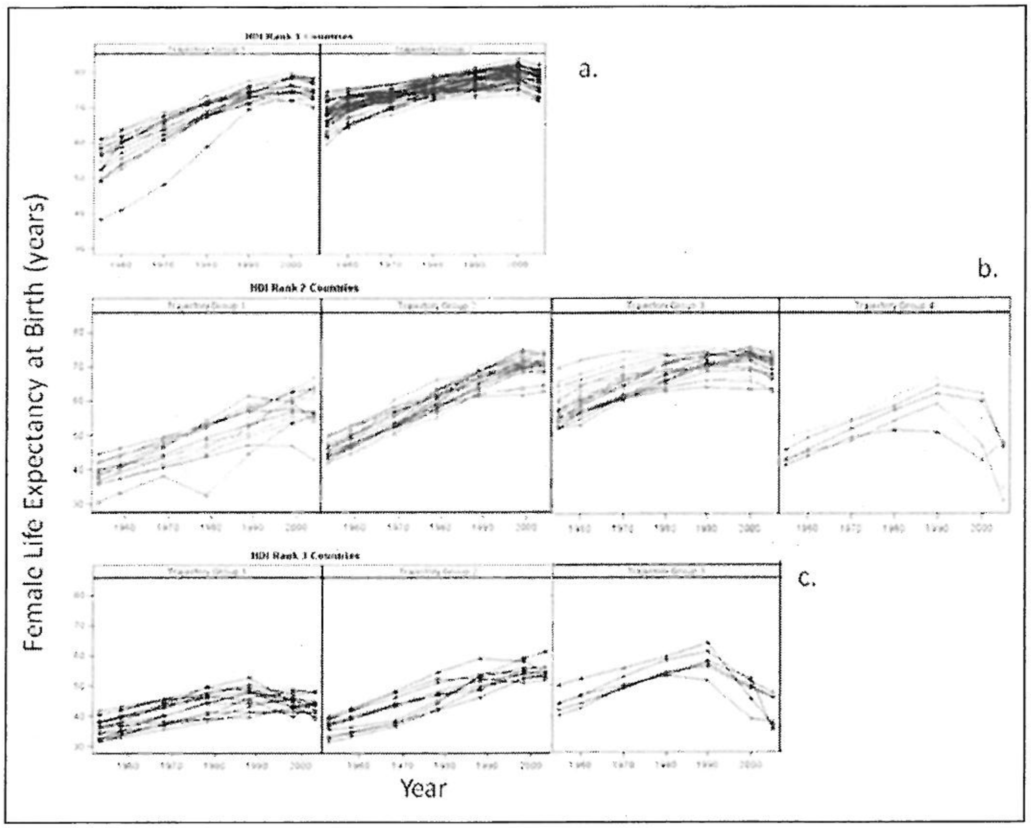

Figure 1. Trajectory analysis graphs showing that female life expectancy at birth is not at equilibrium (See text for further explanation).

Note: When 2 × ΔBIC is 10 or greater, the relationship is considered exceptionally strong. See Results for description. (a) In the best-off countries, two groups are apparent (2 × ΔBIC = 313.44). In one group (HDI1-2), e_0 was relatively high in 1955, and increased slightly; in the other (HDI1-1) e_0 was lower in 1955. (b) Intermediate countries show four trajectories of life expectancy at birth (2 × ΔBIC = 22.1). Life expectancy in the countries of trajectory HDI2-4 (South Africa, Namibia, Botswana, Congo, Uganda, and Swaziland) shows a pattern similar to Trajectory HDI3-3 rank, declining dramatically from about 1990, in part due to increasing prevalence of AIDS. (c) In the worst-off countries, there are three trajectory groups (2 × ΔBIC = 42.52). HDI3-1 began in 1955 with e_0 similar to countries of trajectory HDI3-2, but gained little in life expectancy. In countries of trajectory HDI3-2, life expectancy rose steadily from less than 40 years in 1955 to more than 50 in 2005. Female e_0 in countries in Group HDI3-3 improved from 1955 to 1990, then displayed a precipitous drop.

Timor-Leste (Indonesian occupation and genocide). The most marked improvements in life expectancy occurred in groups HDI2-2 (from mid-1940s to high 1960s) and HDI2-3 (from the high 1950s to the high 1960s).

Female life expectancy at birth in the six countries of trajectory HDI2-4 (Figure 1b; Appendix) increased until 1990, and then declined steeply. Four of these had relatively high proportions of the adult population with HIV in

2005 (South Africa: 18.8%, Namibia: 19.6%, Botswana: 24.1%, and Swaziland: 33.4%). The Congo (also called Brazzaville; 5.3%) and Uganda (6.7%) had a low prevalence of HIV in 2005, but other factors appear important. There has been considerable political instability in The Congo since its independence in 1960, especially around 1990, and it is mostly surrounded by similarly unstable neighbors such as Angola and Rwanda. Uganda is on the eastern border of the Democratic Republic of Congo and the southern border of Sudan and is landlocked (reflecting Collier's [2007] concept of "landlocked with bad neighbors" as a source of disruption). Uganda also saw a large increase in HIV from the first case in 1982, until about 1991, when HIV prevalence reached about 15% among all adults, and more than 30% among pregnant women in cities (Stoneburner & Low-Beer, 2004). Both Uganda and The Congo have the additional disadvantage (Collier, 2007) of having valuable mineral and natural resources that are localized. These are economically defensible by a small group, which leads to conflicts over their exploitation.

Even though e_0 is not at equilibrium, the apparent fit between e_0 and AFB is strong for HDI-1 and HDI-2 countries. There appears, empirically, to be a sort of biological threshold at $e_0 > 60$ (Kaplan, 1997; Low, 1998; Low et al., 2002, 2008). Countries with high HDI rankings and $e_0 > 60$ typically have relatively well-established governance structures in place, facilitating relatively effective responses to health crises and other threats. Of the countries with $e_0 > 60$ in 2005, only the Russian Federation had experienced a noticeable recent decrease in e_0 (from 70.2 to 65.2 years); this shift appears to have had little effect so far on AFB.

Recent Life Expectancy Shifts in Worst-Off Countries

There is striking variation in AFB among HDI3 countries that have (theoretically, at least) the strongest selective pressures for early first birth. This may arise from the highly variable but serious proximate impacts on life expectancy, ranging from HIV to localized resource conflicts, genocide, extreme poverty, and lack of health care. We know little about *how* each of these might affect AFB.

In the 31 worst-off (HDI3) countries for which we have data (Figure 1c), three very different trajectories ($2 \times \Delta\text{BIC} = 42.52$) were identified. Countries in trajectory HDI3-1 (Rwanda, Nigeria, Angola, Malawi, Democratic Republic of Congo, Mozambique, Burundi, Ethiopia, Chad, Central African Republic, Guinea-Bissau, Burkina Faso, Mali, Sierra Leone, Niger) showed a very modest improvement in female e_0 from well below 40 in 1955 to the mid-1940s in 1990, then a small decline. The highest e_0 of any country with this trajectory, in any year surveyed, was 52.5 years for Central African Republic in 1990. Here we suspect a diverse array of causes for declines in e_0. State collapse or retreat is not uncommon, as when the state shows reduced spending on basic human services like health care, typically in response to bankruptcy and structural readjustment. Sometimes this is combined with other stresses, for example, Chad was poor and suffered drought; Burundi had civil war, perhaps leading to state collapse; Democratic Republic of Congo had high HIV prevalence as well as state collapse. Genocide had large impacts on life expectancy in Rwanda. Nigeria had relatively high revenues, but the state collapsed. Most of these countries suffered single-digit declines in life expectancy at birth, so dramatic declines are not evident; however, e_0 was never high. Female e_0 in Group HDI3-2 (Togo, Djibouti, Yemen, Mauritania, Haiti, Gambia, Eritrea, Guinea, and Benin) improved from <40 in 1955 to the mid-1950s to the mid-1950s in 2005. Female e_0 in countries in Group HDI3-3 (Lesotho, Zimbabwe, Kenya, Tanzania, Cote d'Ivoir, and Zambia) improved from 1955 to 1990, then displayed a precipitous drop (cf. Trajectory Group 3 in HDI-2 countries). Three of these countries have a high prevalence of adult HIV (Lesotho: 23.2%, Zambia 17%, and Zimbabwe 20.1%), which may have contributed to the decline.

The pattern of HDI3-3 countries is visually similar to that of the HDI2-4 countries (also African nations: South Africa, Namibia, Botswana, The Congo/Brazzaville, Uganda, Swaziland). However, these visually similar patterns are nonetheless statistically different: $2 \times \Delta\text{BIC} = 9.56$ (considered "strong"). A variety of problems may have contributed interactively to these patterns: rough transitions in public health services accompanying political shifts, for example, in several places, there was a transition from one-party Marxist rule to multiparty democracies and, of course, HIV and AIDS have had a devastating impact on e_0 in some countries.

From 1955 to 2005, most of the world's populations have moved toward longer life expectancies. Figure 2 gives a summary overview of all the patterns and highlights that life expectancy at birth has not been at equilibrium in any group of countries. A constellation of factors have improved living conditions, and fertility and mortality have responded. When e_0 changes dramatically in a short period (e.g., the HIV epidemic in some countries), we should not be surprised at a "mismatch" between the predicted and actual AFB because such biological trade-offs typically do not respond immediately to rapid shifts in a variable. Because we are examining interactions between environmental conditions and genetic composition, mediated by natural selection, we cannot

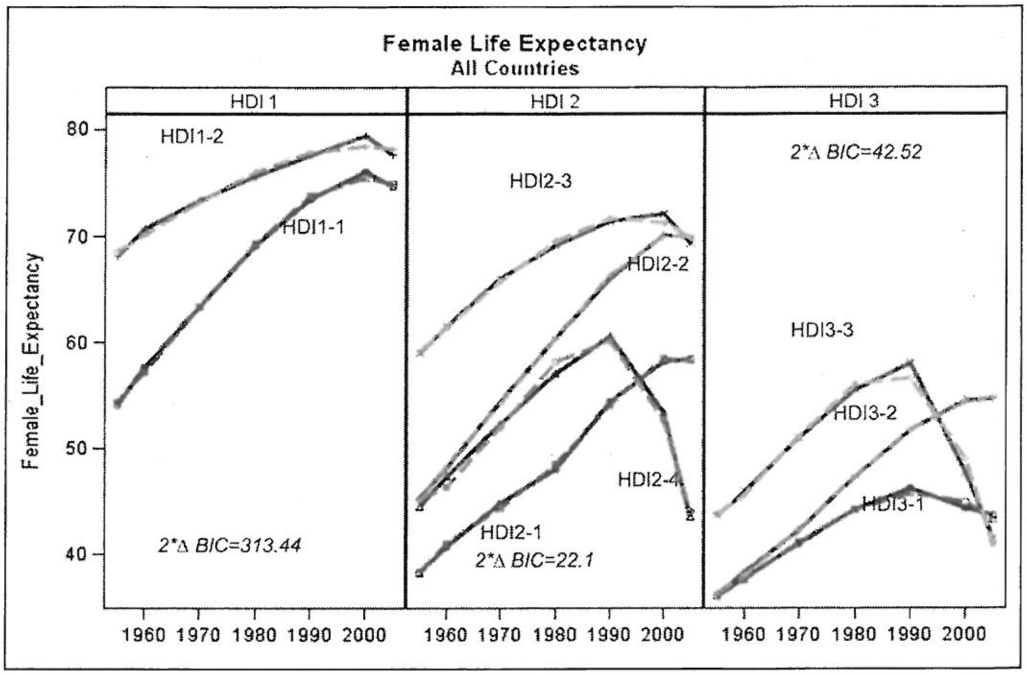

Figure 2. The summary trajectories identified for all countries in the SAS trajectory analysis.

Note: The dotted line in each trajectory represents the model prediction; the solid line represents the empirical data. No trajectories are flat, that is, none are at equilibrium over time. When countries are grouped only on the basis of life expectancy patterns there are clear overlaps across HDI groups. For example, it is difficult to distinguish visually the patterns HDI2-4 and HDI3-3, but see text.

expect a response in less than a generation (which might be possible in cultural transmission). That is, what we see is not simply due to genetic differences, or environmental, or social differences; these interact.

Countries showing a strong recent decline in e_0 of more than 5 years include South Africa, Namibia, and Zimbabwe, all of which have current AFB *later* than expected from their low life expectancies at birth. These are countries that had been relatively stable and well-off; however, recent HIV impacts on life expectancy are dramatic.

High infant and child mortality may change what demographers call "starting, stopping, and replacement" behaviors; that is, the early loss of a child, in the absence of effective birth control use, typically results in a short interbirth interval (rapid replacement) and a resultant high total fertility rate (TFR; e.g., Knodel, 1978, 1987; Low, 1991). It is important to remember for this reason that TFR results in an overestimate of actual population growth because it does not count either infant or maternal mortality, both relatively high in the world's worst-off countries.

HIV and Infant-Child Mortality in Worst-Off Countries: Does Age-Specific Mortality Matter?

In other species, knowing e_0 for any population is assumed to predict AFB well (Harvey & Zammuto, 1985; Stearns, 1992). For long-lived, iteroparous (repeatedly reproducing) species like humans, we might gain more information if we knew more about the *age distribution* of mortality—whether age-specific fertility responds differently to infant, versus young adult mortality. In a regression of e_0 versus under-5 mortality ($R^2 = .815$; Figure 3), we found two very different groups of outliers, marked by different age-specific mortality and different likely causal agents.

Outlier nations above the regression line in Figure 3 include Mali, Niger, Angola, and Sierra Leone. Like so many of their neighbors, these nations all have very low HDI ranks, but child mortality is much worse in these countries than predicted by the general relationship between infant/child mortality and e_0. Both Mali and Niger experience frequent and severe droughts; both are landlocked, reducing ease of imported aid; and both are poor, with GDP/capita measures of $1000 and $700 per year (US$, purchasing power parity corrected). Crippling poverty and failed infrastructure, both of which decrease access to health care, have contributed to extraordinary infant mortality rates. Niger is ranked lowest among all countries in the overall HDI ranking. Angola's and Sierra Leone's positions probably relate to a history of civil wars and invasions. Recently restored peace may have reduced the death rates of older children and reproductive-age adults, but a lagging response in government initiatives and accessible health care means that the youngest members of the population are still dying at high rates.

Outlier nations below the regression line in Figure 3 have lower life expectancies than one would predict from their infant/child mortality rates—Namibia, South Africa, Lesotho, Zimbabwe, Botswana, and Swaziland. One obvious cause is the HIV/AIDS epidemic. In some cases, people suffer from this epidemic in addition to serious poverty and a lack of infrastructure. Several changes are recent. Namibia, South Africa, and Botswana experienced a mostly stable transition from apartheid and colonialism, which made these countries relatively successful at reducing early mortality rates until AIDS became epidemic (UNDP, 2005). Despite stable early postcolonial years, Zimbabwe has experienced recent economic disasters and political corruption. Additionally, it has a very high HIV infection rate.

Together, under-5 mortality rates and HIV prevalence predict life expectancy well both for HDI-3 countries ($n = 31$, $df = 2{,}28$, $R^2 = .866$, std $\beta_{\mathrm{mort}} = -.627$, std $\beta_{\mathrm{HIV}} = -.86$, $p < .000001$), and for countries in HDI-2 and HDI-3

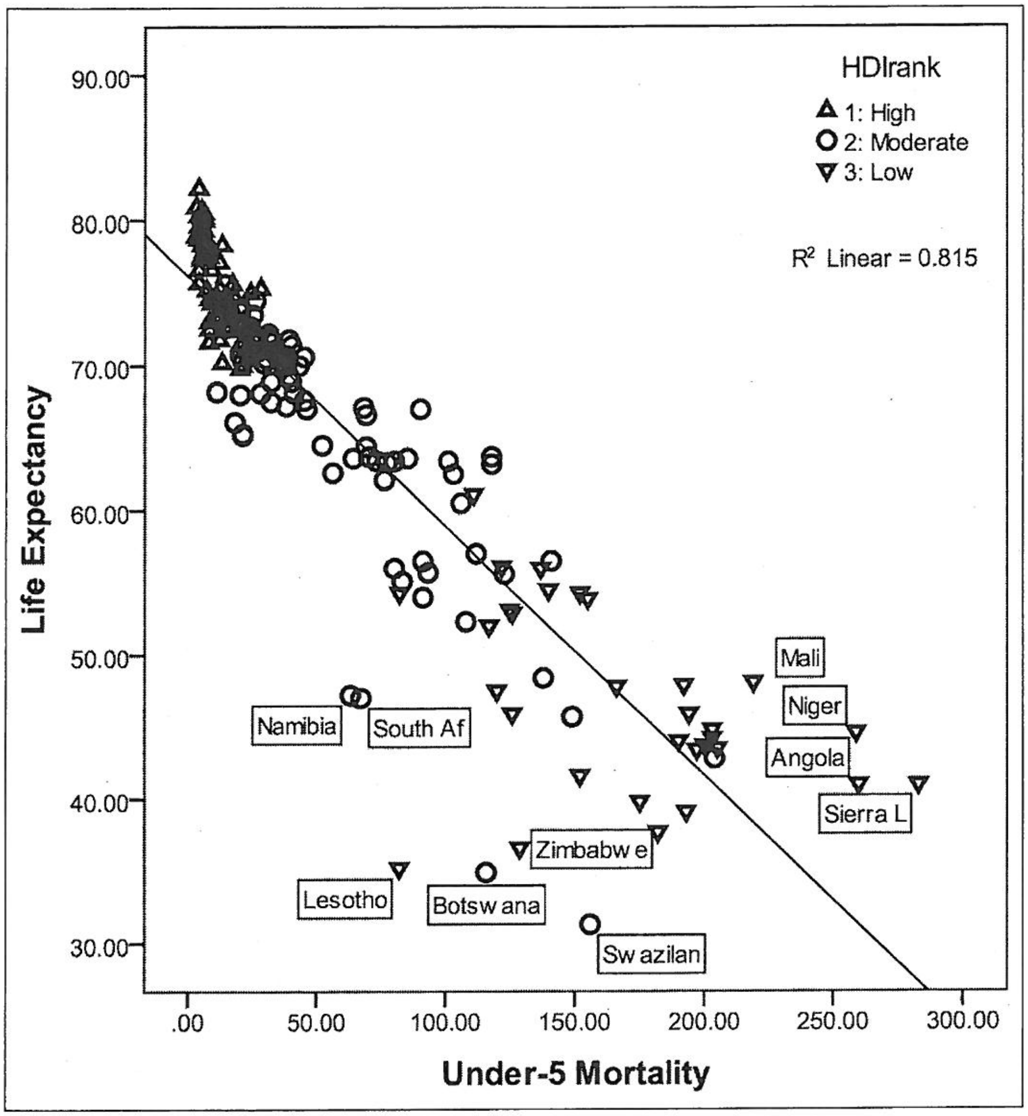

Figure 3. Regression of e_0 versus below-5 mortality ($R^2 = .815$, standardized $\beta = -.903$, $p = .0001$).

Note: High mortality rates clearly influence life expectancy at birth (e_0), but it may be important *when* mortality occurs. Here, outliers are of two sorts. Countries with very high infant and child mortality rates are above the regression line, while countries (mostly high-HIV prevalence countries) in which life expectancy is lower than predicted from the infant and child mortality are below the regression line. See text for further information.

for which life expectancy is less than 60 ($n = 46$, $df = 2, 43$, $R^2 = .871$, std $\beta_{\text{mort}} = -.621$, std $\beta_{\text{HIV}} = -.847$, $p < .0000001$). We suggest that using the empirical break point of 60 years may be important, because some countries designated HDI-2 show life expectancy patterns very like the HDI-3 countries, and this may be important in understanding how to improve conditions.

Does Anything Predict AFB in the Worst-off Countries?

HIV prevalence and under-5 mortality do not predict age at first birth well for HDI-3 countries ($R^2 = .028$). Below-5 mortality appears to shift AFB an earlier age: average AFB was 20.4 for high-HIV countries, and 19.4 for high child-mortality countries. Although both early childhood mortality and adult HIV prevalence can affect e_0, policies aimed at improving life expectancy would focus on quite different strategies in the two conditions.

Women living in the world's worst-off countries have far less control not only over their lives in general but also over their reproductive lives in particular. Interestingly, the best model to predict AFB—for the few HDI-3 countries for which we have sufficient data—uses under-5 mortality, education gap between the sexes, GDI (the gender development index), and female secondary enrollment ($R^2 = .628$, $p = 0.037$, $df = 4, 6$; $\beta_{educ} = .402$; $\beta_{u5mor\,t} = .529$; $\beta_{GDI} = 1.53$; $\beta_{Fsec} = -.916$). Life expectancy contributes nothing to the model.

Many scholars are interested in AFB because across many conditions (Figure 4) it predicts total fertility rate (TFR)—and much policy in developing (and worst-off and "stagnating") countries is aimed at reducing fertility. The best predictors of TFR differ considerably in the worst-off countries, compared to the full sample (Table 2). In the full sample, AFB, HIV prevalence among adults, and under-5 mortality rates are most important (cf. Low et al., 2003). But for the worst-off countries, the strongest model predicting TFR uses AFB, the education gap (ratio of female to male literacy), and the gender development index, a measure of inequality in achievement between men and women. Curiously, adding HIV prevalence did not improve the model.

Life History Theory: Life Expectancy and Risk-Taking

Another basic prediction arising from life history theory is that when life expectancy is short for "extrinsic" reasons (reasons not related to the individual's behavior: high frequency of earthquakes, for example), individuals are likely to take more risks than if conditions are safe and life expectancy is high. For the HDI-3 African countries, HIV prevalence alone and e_0 are significantly related ($n = 31$, $R^2 = .504$, $p = .00001$, standardized $\beta = -.71$) but show some scatter. HIV is an evolutionarily novel virus, first described in 1981 (Barnett & Whiteside 2002). It is problematic for public health officials everywhere: HIV is asymptomatic for a long time, yet it is most infectious in

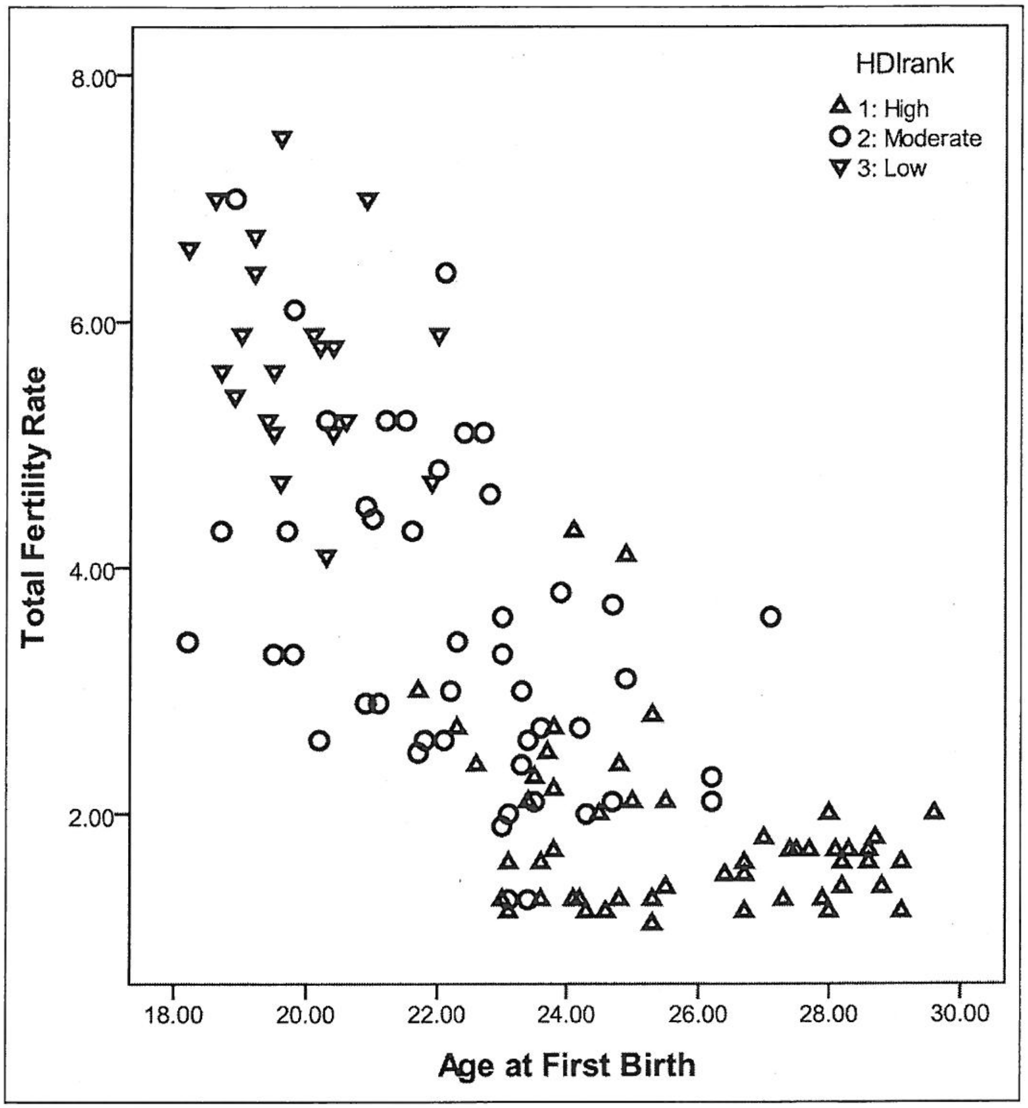

Figure 4. Scatterplot showing that age at first birth (AFB) is, in many circumstances, a reliable predictor of total fertility rate (TFR).

Note: Several western developed nations are outliers, with very late ages at first birth as women opt for education and work before family (cf. Low et al., 2002); ex-Soviet countries tend to have early, but low, fertility, with mothers returning to professional jobs. In the worst-off countries, TFR is not a reliable indicator of actual population growth. Because it ignores both infant/child and maternal mortality, it overestimates population recruitment.

the first couple of months after exposure (Jacquez et al., 1994), enabling it to spread rapidly. Furthermore, teaching people about the risks of unprotected sex makes little difference: HIV/AIDS knowledge and perceived risk of infection often do not correlate with riskiness of sexual behavior (e.g., Adetunji & Meekers, 2001; Boer & Mashamba, 2005).

Table 2. The Strongest Models for Predicting Total Fertility Rate (TFR) in the Full Sample, and in the Much Smaller Sample of Worst-Off Countries (HDI-3).

Sample	*N*	*df*	R^2	TFR predictors	Std β	Model significance
Full	123	1, 121	.772	AFB	−0.236	$p < .0001$
				HIV	−0.032	
				<5mortality	0.686	
Worst-off countries	12	3, 8	.671	AFB	−0.255	$p = .007$
				education gap	−0.409	
				GD I	−0.366	

If low extrinsic e_0, particularly due to mortality after young childhood, leads to risky sexual behavior as well as early first births, HIV infection should rise rapidly in countries with already low e_0 (e.g., by 1990). This appears to be true, although our data are only correlative, and there are several potential covariates. For countries with female life expectancy at birth of 60 or better in 1990, the average HIV infection rate in 2005 was 1.19%. In contrast, for countries with low female life expectancy at birth in 1990 (< 60), the HIV infection rate in 2005 averaged 4.38%. Of countries with current adult HIV prevalence greater than 10%, only Botswana is a puzzle. Central African Republic, Lesotho, Malawi, Mozambique, Swaziland, and Zambia all had e_0 less than 60 in 1990 (range = 42-57); Namibia, South Africa, and Zimbabwe were all at or below the breakpoint of 60 years.

Botswana's female e_0 for 1990 was 65.1. Botswana responded quickly to the HIV threat: its first AIDS case was reported in 1985 and by 1987, it began blood screening. The first African country to provide anti-HIV drugs, Botswana also offered broad-based responses, including education, beginning in 1989 (AVERT, 2011). Nonetheless, the 2005 adult HIV prevalence stood at 24%. This high prevalence may be because sexual practices are strongly influenced by social and cultural factors, from the marriage system to social acceptance of sexual activity for various groups. In some areas of Botswana, an expressed preference for "dry sex" means that tears in the vaginal wall are likely, and they facilitate the spread of HIV.

Norms, expectations, and attitudes undoubtedly contribute to variation in the reproductive patterns we see although we did not find strong evidence of such norms in our data. Similarly, Inglehart and Baker (2000) used data from three waves of the World Values Survey for 65 countries (52 in common with our sample). They examined people's attitudes on two axes: Survival/Self-Expression, and Traditional/Secular-Rational, asking about family size preference, degree of religiosity, acceptability of divorce, obedience of women to their husbands, women as political leaders, and desirability of two parents in a household. We examined these data for our full sample in relationship to AFB and HIV. Not surprisingly, AFB tended to increase somewhat with more "rational" (R^2 = .308) rather than "traditional" values, and with more "self-expression" (R^2 = .341) rather than "survival" attitudes, but there was considerable scatter. HIV prevalence relationships were weak to nonexistent with both traditional values (R^2 = .152) and survival attitudes (R^2 = .006).

For the present, we simply note that if a low life expectancy leads to time-discounting, that discounting may in turn lead to risky sexual behavior (e.g., Anderson et al., 2007), and worsen the problem. Some widely promoted strategies such as education, for example, about HIV transmission, dry sex, and so forth, may not have the impacts we hope.

Women's Lives in Worst-Off Countries

The Gender Ratio provides a direct comparison of women's lives to men's. Low (2011) found that both the mean (ANOVA: $df = 2, 133$; $F = 32.036$; $p < .000001$) and the variance (Levene statistic = 25.73, $p < .00001$) of the Gender Ratio differ across the best-off, moderate, and worst-off countries. In post hoc comparisons, the Gender Ratio in each level differed significantly from both other levels at $p < .002$ or greater. The worst-off HDI-3 countries, not surprisingly, had relatively low Gender Ratios overall. Women's lives in these countries are more constrained than women's lives in better-off nations (Low, 2011).

What correlates with the Gender Ratio in worst-off countries? In the 24 low-HDI countries for which there are data, the Education Index and Female Employment were most significant in stepwise regression (df 2, 22; $R^2 = .499$, $p < .0001$; $\beta_{educ} = .546, p < .001$; $\beta_{fememp l} = .559$; $p = .018$; see Low, 2011 for comparisons to higher-ranked countries).

Women in the best-off nations are paid less than men for many comparable jobs. In addition, working mothers often have a harder time in the job marketplace than others, and the cost of professional success is often childlessness for women (e.g., Smock & Noonan, 2005). However, these inequities pale compared to the restrictions on women's roles in the worst-off countries. The UNDP measure GEM, which reflects women's effectiveness in economic and political spheres, differs across the HDI groups (ANOVA, $df = 2, 72$, $F = 28.7$, $p < .00001$). No post hoc pairwise comparisons were significant (HDI-3/HDI-1, $p = .636$; HDI-3/HDI-2, $p = .963$), suggesting no interactions are statistically important.

Discussion and Concluding Remarks

The complexity of interpopulational variation in the relationships among life expectancy at birth and age at first reproduction shows clearly that the two assumptions we typically make in such analyses for other species are not met in humans: (a) no single population would be a good representative of the relationships, and (b) in many, perhaps most, cases, an important variable is not at equilibrium. We acknowledge that humans show great complexity, but suspect that many other species will, on examination, also prove not to meet the common assumptions.

Within-Nation Analyses Inform Cross-National Research and Vice Versa

The patterns here are, as we noted, national "averages"; even so, they are informative about implicit assumptions regarding the equilibrium status of important variables. We are well aware that more variation exists than we can show here. Because nations are not singular, homogeneous populations, even when national data suggest a mismatch among life expectancy, AFB, and TFR, there may be further within-nation differences, as a result of varying cultural (including religious) practices. For example, in Namibia and South Africa, conditions for a wealthy subset of the population have remained relatively stable and economically competitive. In response, that subset adopted western fertility patterns (late AFB, lower total fertility), leading to high within-country variation (author's data: AH).

Furthermore, because nations typically represent multiple populations with differing conditions, and thus different optimal life history paths (e.g., Low, 2000b, 2007; Low et al., 2002; see also Wriggley & Schofield, 1981), within-nation studies would contribute greatly to our understanding. In 19th-century Sweden, for example, daughters of wealthy men tended to marry wealthier men at relatively young ages; daughters of poorer men married poorer men at slightly older ages (Low, 1989, 1990; Low & Clarke, 1991). Compared to daughters of poorer men, wealthier daughters experienced earlier AFB, similar interbirth intervals, but similar ages at last birth—and averaged about 1.5 more children than did poorer women (Low, 1989, 1990, 2000a, 2000b; Low & Clarke, 1991). Wealth affected AFB, e_0, and total fertility.

In the United States today, the relationship between a woman's own earnings and her fertility differs between Black and White women (Taşiran, 1995). Poor urban Black women and White women on welfare have a short life expectancy and early (but not high) fertility compared to better-off White women in the United States (Geronimus, 1996a, 1996b, 2001; Geronimus et al., 1996; Rank, 1989; also Low et al., 2002). Similarly, when a U.S. woman's first birth is nonmarital, the impacts on the rest of her reproductive life differ with her ethnicity (Anderson & Low, 2003).

In our data, Gabon may also show considerable within-country variation not reflected by national-level data. It is relatively well-off (GDP/capita = $6623, well above the average of sub-Saharan Africa), but its main wealth today comes from offshore oil, which represents 50% of the GDP. No Gini figures are available, but it appears wealth is concentrated among a few elites (cf. Collier, 2007). Because age-specific fertility and AFB vary with familial wealth in many conditions, understanding within-country variation in age-specific fertility would be informative, especially in countries with high income inequity.

Egypt, too, has high within-country variation. It has been undergoing a "slow fertility decline" since the 1960s (Vignoli, 2006). It also exhibits compressed fertility: late AFB, yet short interbirth intervals and higher-than-replacement fertility. Age contributes to this variation: older, childbearing-age couples tend to want three or more children; in contrast, more than half of younger adults desire lower fertility (Casterline & Roushdy, 2006). Fertility is lowest among educated urban women (Casterline & Roushdy, 2006; cf. Low et al., 2002), and within-country variation appears to split largely along urban-rural, and northern-southern lines. There may be religious influences as well.

The national average AFB for Israel is extraordinarily low (21.7 years) for its relatively high life expectancy at birth (74.8 in 1980, 77.4 in 1990, 80.2 in 2005). This may reflect the fact that Israel is a heterogeneous society; a number of factors may create variation (Nahmias & Stecklove, 2007; Schellekens & Anson 2007): ethnicity, urban-rural residence, place of birth, religiosity, and perhaps even perceived mortality risks.

One case in which locally measured attitudes about sexual practices appear to be changing is Thailand, where HIV-awareness is relatively good. HIV is relatively restricted, associated with tourism and the sex industry, and its overall prevalence is low (1.4%). John Knodel and colleagues (1997) interviewed married men and women in urban and rural contexts about sexual attitudes. Women had no control over their husbands' spending evenings with male friends and sex-workers; most women preferred (as in the past) that their husbands visit sex workers rather than having minor wives—the cost of a sex worker was minimal and the transaction quickly completed. A minor wife can represent a significant drain on the primary wife's and children's resources. However, some women explicitly stated that the presence of HIV had changed their minds: they thought the lower health risk of a minor wife would be worth the extra loss in resources (Knodel et al., 1997).

Currently, there are only a few fine-grained life-history analyses, such as those above, of modern data in developing and least-developed nations. Analyses exist for traditional societies and some historical and modern societies. Differences across cultural subgroups are common in traditional and historical societies (see a review by Clarke & Low, 2001). But such fine-grained analyses are not systematically available or even always comparable. It is difficult to draw general conclusions without a broader framework. We suggest cross-national life history analyses not only provide a context for examining finer grained data when they become available, but can help us look for general patterns and highlight potentially interesting within-nation variation. Rich and interesting explorations await; our beginning analyses, we hope, at least highlight why these cases are of interest.

Methodological Limitations ofThis Research

The HDI ranking, because of its compound nature, can assign the same overall rank to countries with quite different life expectancies (e.g., the e_0 for midranked HDI countries ranges from 31.3 years in Swaziland to 75.6 years in Dominica). In addition, because e_0 is included in calculating HDI, high-HDI countries have e_0s over the apparent "threshold" (Low et al., 2008) of life expectancy at birth of >60 years (range 69.8-82.2). National-level indicators have potential inconsistencies. In particular, data for countries falling at the low end of the HDI are likely to be missing, or less reliable, than data collected from highly ranked nations, in part because of differences in infrastructure effectiveness and political stability. Some data are missing (e.g., we still lack data on "Children Underweight for Age" for 35 countries), which reduces our sample size for some questions. Our results should therefore be understood as preliminary.

As we noted above, the compound nature of the HDI rank also means that highly specific rankings can simply be inaccurate. Wolff et al. (2011) note that a combination of factors (combined ranking rising from original variables that measure quite different things, so that a country may score low overall for failures in quite different aspects) renders any country's HDI unreliable except at rather crude levels. Statistically, a country may have a rank misassigned by as much as nine levels, so that using a few categories, as we do here, reduces the introduction of potential inaccuracies. Thus the HDI is a reasonable rough indicator, but for questions of life expectancy, for example, it is only a very crude grouping. Trajectory analysis is more revealing.

Biological Relationships and Policies Affecting Women's Lives

In exploring the human complexities within a very broad life-history relationship—that between e_0 and AFB—we have uncovered a series of interactions that need more exploration. Life expectancy helps shape AFB, but the relationship itself is neither "species-typical" in any population, nor at equilibrium. Both institutional support such as family planning and basic health care, and norms (marriage preferences, abortion rules) interact and modify each other, just as ecological pressures do.

If life expectancy is not stationary over time, the relationship between e_0 and AFB may also be in flux, and mismatched—at disequilibrium. Thus rapid changes in e_0 can create disequilibrium and mismatches between e_0 and AFB. Quite different age-specific mortalities can generate similar overall e_0s. These underlying biological relationships may seem esoteric, but we argue that they may help us find more effective strategies as we explore their connections.

The concept of equilibrium is not widely considered in the cross-cultural or demographic literature—and it may be overassumed within biology. The hypothesized and generally strong relationships among e_0, AFB, TFR, HIV prevalence, and under-5 mortality can become mismatched if any one of the variables is changing rapidly. And, if any of those variables change, the relationship between the changed variable and others will likely become a mismatched "outlier." Thus it is important when doing life history analyses to know whether variables in a hypothesized relationship are changing rapidly.

Some social indicators of concern to policy makers (e.g., proportion of births attended by professionals) might be expected to have clear and direct relationships to e_0 and AFB—but for women in the worst-off countries, we found no patterns. For other measures (e.g., level of female secondary school enrollment, female work force participation), there is no clear link with e_0—yet they might help shape women's AFB through mores and practices . We would consider these as sociocultural influences well worth more study.

Particularly in worst-off nations, serious ecological constraints matter: for many of the worst-off countries, the proportion of arable land is small, and in some regions, the entire country may be drought-ridden. Many countries also have chronic high disease risks like malaria and HIV. The presence of valuable and localized natural resources, easily controlled by small groups, may lead to almost-continual conflict (Collier, 2007).

Without the expectation of a long and healthy adult life, there is little incentive to adopt new fertility-delaying opportunities. Furthermore, because HIV risks are "silent" for a long period, we may see a positive feedback loop: the risk is undetectable but real, and may well lead to riskier sexual behavior simply because no clear feasible alternative exists. That is, because life expectancy at birth is low already (due to extrinsic factors), women have sex and children early in their lives, even when engaging in sex carries the risks of becoming infected with HIV, *further* lowering their life expectancy. All of these factors contribute to a continuing cycle of early birth and short life expectancy in worst-off countries.

Life-history theory led us to make comparisons that are atypical for much cross-cultural work. Perhaps ethnographers and other social scientists will find it useful to incorporate a few important biodemographic measures (overall e_0, age-specific mortality, AFB, age-specific fertility) more routinely for studying human populations, as we strive to understand both social and ecological proximate drivers of fertility at fine-scale local levels. Although this is novel, perhaps it will allow us to understand these relationships better and even perhaps allow policy makers to predict better the consequences of some cultural and social pressures—even when those pressures cannot be accurately measured in all their complexity. Many factors complicate the picture: extreme poverty; spotty, sometimes unreliable aid; poor health care infrastructure; civil conflicts with real or perceived impacts on mortality; large within-nation variation in both norms (ethnic, religious, and marital rules) and governance impacts such as differential access to family planning. These factors can create rapid shifts in e_0, resulting in nonequilibrium, and mismatched patterns. Identifying relatively local and inexpensive approaches to changing key life history variables, like decreasing below-5 mortality, is already standard practice for population and development policy makers. Our point here is that if we understand how core biological relationships affect social phenomena, and vice versa, we may be able to promote ripple effects like later first births, and broader spacing of births in some of the world's worst-off countries—and if we can, these will affect women's lives in beneficial ways.

Appendix

Countries in Each Trajectory Group

HDI1-Trajectory 1: Bahamas, Bahrain, Bosnia and Herzegovina, Brunei Darussalam, Chile, Costa Rica, Korea (Republic of), Kuwait, Malaysia, Mauritius, Mexico, Oman, Panama, Qatar, Tonga, Trinidad and Tobago, United Arab Republic

HDI1-Trajectory 2: Argentina, Australia, Austria, Barbados, Belgium, Bulgaria, Canada, Croatia, Cuba, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hong Kong, Hungary, Iceland, Ireland, Israel, Italy, Japan, Latvia, Lithuania, Luxembourg, Malta, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Singapore, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom, United States, Uruguay

HDI2-Trajectory 1: Bangladesh, Bhutan, Bolivia, Cambodia, Cameroon, Comoros, Equatorial Guinea, Gabon, Ghana, India, Laotian People's Republic, Madagascar, Maldives, Myanmar, Nepal, Pakistan, Papua New Guinea, Sudan, Timor-Leste

HDI2-Trajectory 2: Algeria, Cape Verde, China, Dominican Republic, Ecuador, Egypt, El Salvador, Guatemala, Honduras, Indonesia, Iran, Jordan, Libyan Arab Republic, Mongolia, Morocco, Nicaragua, Occupied Palestine, Peru, Philippines, Samoa, São Tomé and Principe, Saudi Arabia, Solomon Islands, Syrian Arab Republic, Tunisia, Turkey, Vanuatu, Viet Nam

HDI2-Trajectory 3: Albania, Armenia, Azerbaijan, Belarus, Belize, Brazil, Colombia, Fiji, Georgia, Guyana, Jamaica, Kazakhstan, Kyrgyzstan, Lebanon, Macedonia, Moldova (Republic of), Paraguay, Russian Federation, Saint Lucia, Saint Vincent, Sri Lanka, Suriname, Tajikistan, Thailand, Turkmenistan, Ukraine, Uzbekistan, Venezuela

HDI2-Trajectory 4: Botswana, Congo, Namibia, South Africa, Swaziland, Uganda

HDI3-Trajectory 1: Angola, Burkina Faso, Burundi, Central African Republic, Chad, Congo (Democratic Republic of), Ethiopia, Guinea-Bissau, Malawi, Mali, Mozambique, Niger, Nigeria, Rwanda, Sierra Leone

HDI3-Trajectory 2: Benin, Djibouti, Eritrea, Gambia, Guinea, Haiti, Mauritania, Senegal, Togo, Yemen

HDI3-Trajectory 3: Côte d'Ivoir, Kenya, Lesotho, Tanzania, Zambia, Zimbabwe

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