Age-Specific Fertility Dynamics: Sub-Saharan African Fertility in a Global Context

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Abstract

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Persistent high fertility in sub-Saharan Africa has been of concern to demographers and global health experts for decades. Sub-Saharan African fertility levels and trends are singled out as markedly higher and different than the rest of the world and from what is expected based on historic fertility trends. Global population projections, which indicate continued population growth in sub-Saharan Africa while population stabilizes and declines elsewhere brings renewed focus on African fertility. This dissertation seeks to address some of the challenges to understanding modern fertility regimes and fertility dynamics posed by persistent high fertility in sub-Saharan Africa by examining it in a global, demographic context.

Population measures of sterility are traditionally constructed for women, despite fertility and sterility being conditions of the couple. Estimates of male sterility provide insight into population-level sterility and complement estimates based solely on women. Chapter 2 seeks to estimate male sterility for the Gwembe Tonga of Zambia using male birth histories collected by the Gwembe Tonga Research Project from 1957 to 1995, while providing context by estimating female sterility for the Gwembe Tonga as well as female sterility in all of Zambia from Zambian DHS data (1992, 1997, 2001-02, and 2007). Sterility is measured using the Larson-Menken *subsequently infertile* indicator. Estimates are produced using discrete time

event history analysis. The odds of sterility were higher for women than men, though womens odds of sterility were only 1.5 times that of mens in the middle reproductive years. The odds of sterility increased steadily with age for both men and women, and across all datasets. However, womens sterility increased much more sharply with age than mens and womens odds of sterility were higher than mens at all reproductive ages.

Chapter 3 aims to understand trends in global fertility from 1950-2010 though the analysis of age-specific fertility rates. This approach incorporates both the overall level, as when the total fertility rate is modeled, and different patterns of age-specific fertility to examine the relationship between changes in age-specific fertility and fertility decline. Singular value decomposition is used to capture the variation in age-specific fertility curves while reducing the number of dimensions, allowing curves to be described nearly fully with three parameters. Regional patterns and trends over time are evident in parameter values, suggesting this method provides a useful tool for considering fertility decline globally. The second and third parameters were analyzed using model-based clustering to examine patterns of age-specific fertility over time and place; four clusters were obtained. A country's demographic transition can be traced through time by membership in the different clusters, with regional patterns in the trajectories through time and with fertility decline.

Generally determinants of fertility decline are hypothesized to encourage declines at specific ages as a result of the mechanisms by which these determinants exert influence on fertility. Using the reduced parameterization of age-specific developed in this dissertation, Chapter 4 aims to examine the association of determinants of fertility with age-specific fertility curves to test hypotheses regarding how determinants of fertility decline are associated with age-specific fertility. Results of this analysis corroborate predictions made in the literature about how age-specific fertility is affected by mortality, development, HIV prevalence, women's empowerment, contraception use and urbanization. However, some hypotheses were not born out, notably the association between low mortality and stopping behavior. The evidence indicates that these relationships are not uniform across world regions and that these relationships are different across world regions.

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Chapter 1

INTRODUCTION

Persistent high fertility in sub-Saharan Africa (SSA) has been of concern to demographers and global health practitioners for decades, as SSA fertility trends are singled out as markedly different (higher) than the rest of the world and than expectations based on historic fertility trends elsewhere. Demographic transition theory would posit that once begun fertility decline should be relatively steady and irreversible, and most demographers agree that fertility decline had begun in almost all of SSA by the late 1980s (see Bongaarts and Casterline, 2013) or the 1990s (see Caldwell et al., 1992). However, the most recent population projections projected an increase in world population, reaching 9.7 billion by 2050, and more than half of that growth in SSA (United Nations, 2015b). Additionally, analysis of the convergence of fertility has demonstrated that high fertility in SSA has been the outlier in global fertility convergence for decades (Dorius, 2008). The UN projections revisions and Africa's projected population growth were widely reported in the news at the time of the 2013 revision (see Fisher, 2013), and, since publication, these revisions have been used as evidence of African population pressures causing concerns for various global blights, such as antibiotic resistance (Hamblin, 2014), food security (Porter, 2014; Keyworth, 2013), and African development (Economist, 2014). These are serious concerns, but their gravity and probability of catastrophe occurring can really only be understood if we understand SSA population dynamics and particularly fertility trends in a global context. Demographic transition theory, in any of its iterations, fails to fully explain modern fertility trends in SSA, and this failure has led to theoretical and empirical work that seeks to understand the pace of fertility decline in SSA, and whether or not fertility decline in some countries has stalled. However, no definitive explanation has yet been put forth that situates and explains SSA fertility trends within global fertility trends and demographic transition theory satisfactorily. Additionally, it is important to note that in the mid-20th century, similar concerns about the impending Asian population explosion were common, and used as a call for studying and controlling Asian fertility (see Davis, 1946).

This dissertation seeks to address some of the challenges to understanding modern fertility regimes and fertility dynamics posed by persistent high fertility in SSA. First, this chapter provides a literature review of SSA fertility trends since the 1990s, focusing on the slow decline and possible stalls in fertility decline. The different theories and empirical work presented here motivate the hypotheses that will be tested in this dissertation. Chapter 2 is a paper analyzing male and female sterility in Zambia to demonstrate the role of age in the decline of fecundity for both sexes[1]. Chapter 3 presents a quantitative characterization of fertility schedules, and resulting classification of fertility regimes, to facilitate global comparison of age-specific fertility regimes through time. Chapter 4 uses the parameter values obtained in Chapter 3 to test whether commonly hypothesized determinants of fertility decline are significant predictors of the shape of fertility curves, testing whether factors related to fertility are associated with the shape of age-specific fertility curves.

1.1 Sub-Saharan African Fertility Transitions: Generally and Briefly

Sub-Saharan Africa (SSA) is the last world region to undergo fertility transition and has seen the slowest decline. The transition in SSA is the most recent and SSA began its transition at, and currently has, the highest fertility. Figure 1.1 shows trends in total fertility rates

[1]This work has been published in *Demographic Research*: Pantazis, Athena, and Samuel Clark. "Male and female sterility in Zambia." Demographic Research 30 (2014): 413-428.

(TFR) for the world and world regions, and SSA regions from 1950-55 until 2005-10. SSA, including East Africa, West Africa and Central Africa have curves that, despite some evidence of decline, remain at high levels of fertility, while all other regions of the world have seen a steady decline through the last half of the 20th Century, with TFRs well below 4 by 2005-10. Only the Southern African transition, led by South Africa, resembles the transitions seen elsewhere in the developing world (Shapiro, 2012). Shapiro (2012) highlights the lower levels of women's education in SSA compared to other regions of the developing world as a plausible factor contributing to this difference in transition. According to Bongaarts and Casterline (2013), most of SSA is still early in the transition with high fertility, citing the different reproductive behaviors in African countries, compared to non-African countries. The transition did not begin in SSA until at least the 1980s, and the fertility levels at the beginning of the transition were higher in SSA than they were elsewhere at the onset of fertility decline; the average total fertility rate of 6.5 in SSA compared to 5.8 elsewhere (Bongaarts and Casterline, 2013). Additionally, the recent pace of the fertility decline in SSA is much slower than the pace of decline in Asia and Latin America in the 1970s. Ideal family size in SSA pre-transition was higher, by about 1 child, than ideal family size in pre-transition Asia, and while ideal family size and TFR are closely correlated and have declined in almost all countries, at any TFR ideal family size is higher in SSA than in Asia or Latin America and ideal family size in SSA remains higher (at about 4.6) than it was in Asia pre-transition (Bongaarts and Casterline, 2013). The persistent high fertility in SSA, in addition to being a subject of importance for population projections, has posed challenging to incorporate into demographic transition theory, resulting in a few debates about the mechanics of fertility decline, which are discussed below.

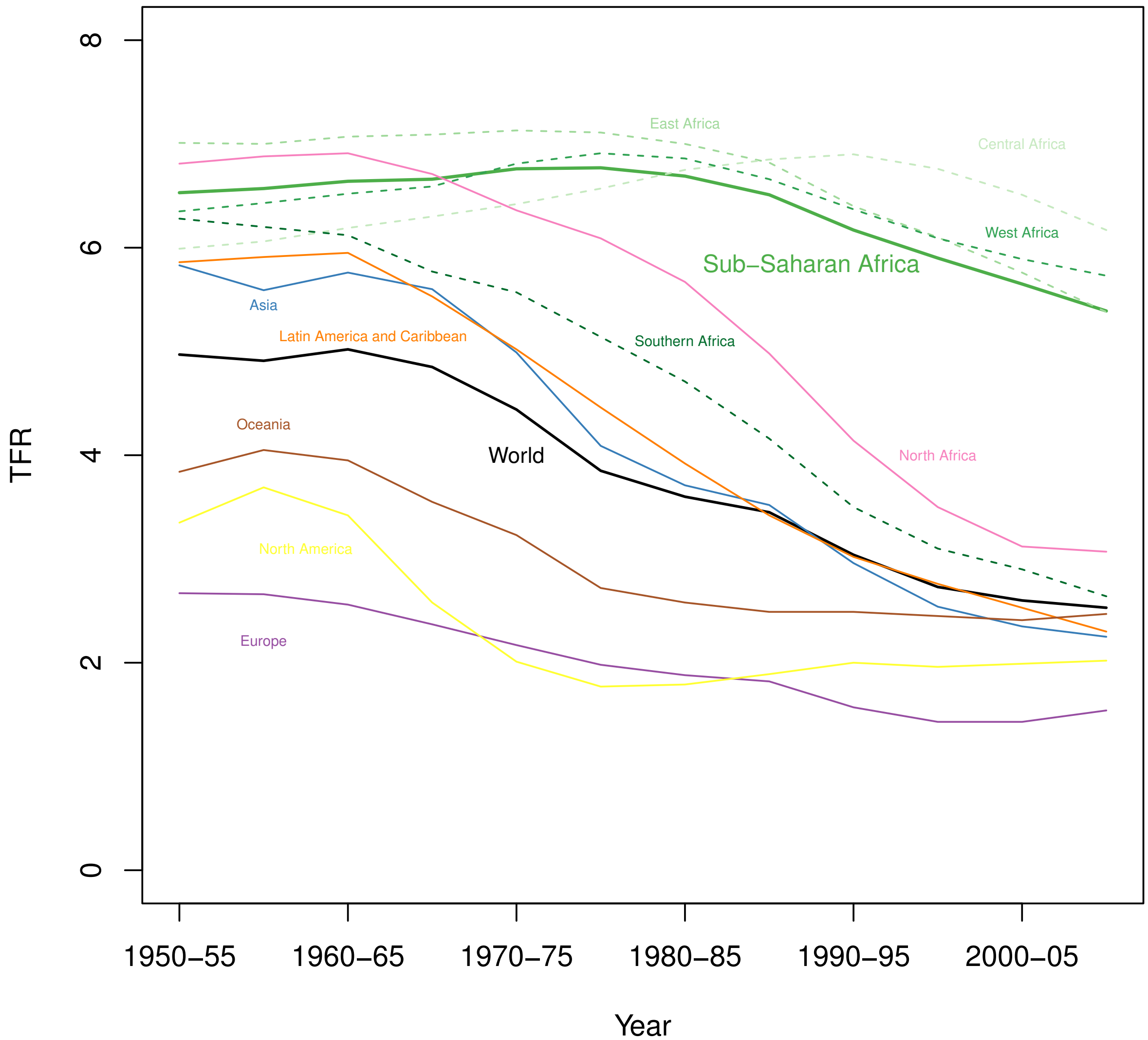

Figure 1.1: World Fertility Trends, with sub-Saharan Africa sub-regions. Data from (United Nations, 2013)

1.2 Onset of Fertility Decline

To analyze the patterns of fertility declines, demographers must be able to identify when fertility decline begins, frequently referred to as the onset of fertility decline in the literature. While identifying the start of decline seems like it should be straightforward, and perhaps is for historical transitions that are well underway or have finished at the time of analysis, there remains debate in the literature about the best way to operationalize the onset of decline in real time or for the recent past. Theories seeking to explain demographic transition must account for the different circumstances in which fertility decline begins in some way, and debates between socioeconomic and cultural causes of fertility transition frequently invoke the vast differences in socioeconomic levels under which modern societies begin fertility transition in their argument (Bryant, 2007).

There are subtle differences, though real ones, in the definitions of fertility decline onset used by researchers analyzing patterns of fertility transition. Bongaarts and Watkins (1996) define the start of fertility decline as the year at which there has been a fall of 10% from the pre-transition maximum, using the Princeton European Fertility approach which was used because no European countries saw fertility increases again after meeting this threshold. Casterline (2001) critiqued this threshold as potentially being later than the actual decline onset, and in cases where the decline was slower the lag between the actual onset and the onset determined this way would be longer. Instead, Casterline (2001) uses the peak as the onset so long as the TFR has declined by at least 10%. Alternatively, he suggests that if the TFR is between 2.5 and 5.5, then one can say that fertility decline is underway. Bongaarts (2002) accepted Casterline (2001)'s critique and used 5% as the decline threshold; in cases where TFR rose again after a 5% decline, then the onset is placed after the subsequent peak. Bryant (2007) uses a similar definition of onset for his fertility transition analysis to that of Bongaarts (2002), where the onset is defined as peak before the TFR declines by 5%, so long as the TFR does not increase again. If TFR increases, then the new peak is used as the onset, but a date can only qualify as the onset of decline if TFR declines by at least 0.25 births in the next five years (Bryant, 2007). More recent population projections have made use of a slightly different definition of the onset of fertility decline; the onset is set as the most recent local peak that is within 0.5 children of the overall peak, and if this local peak is above 5.5 it is the onset. Peaks below 5.5 indicate that the fertility decline began before the period under study (1950-55) (Alkema et al., 2011). Bryant (2007) used data from the UN WPP and looked at indicators for per capita gross domestic product (GDP), life expectancy at birth, measures of education, percent of the population living in urban areas, and the relative size of the agricultural sector, and finds that while fertility decline is associated with socioeconomic development, the strength of the relationship between the level of development and onset of fertility decline shifts with different operationalizations of the onset.

If one thing is clear from these varied, though similar definitions, it is very challenging to identify the date of onset of fertility decline if it is has only just happened and fertility levels remain high, i.e. that the country is still in the early stages of fertility transition. Generally, demographers agree that TFR must be at 5.5 or lower for decline to be underway, but as discussed in the works cited above and in the overview of SSA fertility transition, many countries have had TFRs above or around 5.5 for many periods of measurement. In these cases it is very difficult to apply any of these techniques for determining the onset of fertility decline. Demographic transition theory states that the period of high fertility will see fluctuation at this high fertility levels, thus without sustained decline, it is challenging to determine whether fertility decline is underway or instead that these are the local peaks and valleys of a high fertility period.

1.3 The Pace of Fertility Decline

Once the fertility decline is determined to have begun, as most researchers agree it has in most countries in the world, the fertility transition is underway. However, particularly in the last half of the 20th century, the paces of the fertility decline, and the length of time the transition to low fertility takes, has varied greatly across countries. The original theorizations of demographic theory do not provide insight into the determinants of pace, but as countries in Asia, Latin America and SSA have undergone fertility decline, different explanations about the differing paces have been offered. Bongaarts and Watkins (1996), looking at fertility trends for 69 developing countries from 1960 to 1990, found substantial variation in the pace of decline and no correlation between the rate of change in development indicators and the rate of fertility decline. However, they did find that the pace of fertility decline was associated with high socioeconomic development markers at the beginning of the fertility decline; countries with high levels of development experienced rapid declines.

One common finding is that the pace of SSA declines is distinctly slower than elsewhere in the world (Shapiro, 2012). Casterline (2001) used the UN's WPP data and estimates from 1996 to analyze the pace of fertility decline for 94 countries with a population of at least one million, excluding those whose transitions were well underway by 1980. In the last half of the 20th century, transitions in the developing world had not been speeding up, despite rapid decline for some countries. For SSA, Casterline (2001) found only Ghana and Botswana were experiencing substantial fertility decline and that, in general, SSA declines were slower than Latin America and Asian regions. He argues that this finding should not be surprising because societies that were most receptive to fertility decline started first and countries with late declines are those "societies that are relatively resistant to decline" (Casterline, 2001). Casterline (2001), building on the work of Bongaart and Lee and Galloway and Hammel's adaptation of Easterlin's relationship between fertility, natural fertility, desired surviving children, willingness and ability to avert births and expected child mortality, posits that pace of decline is a positive function of: a) the pace of social and economic change; b) the pace of change in economic aspirations and expectations, that is the growing of disparity between economic expectations and reality and the awareness of that disparity; c) the pace of improvement of birth control services; and d) the pace of reduction in the moral and social costs of birth control. Using more recently available data, Bongaarts and Casterline (2013) find the recent pace of fertility declines in SSA is slower than the pace of decline in Asia and Latin America in the 1970s; the median pace of change is 0.03 per year, less than a third of the pace of other regions.

1.4 Fertility Stalls

The slow pace of fertility decline in SSA, much slower than the earlier declines in Latin America and Asia, has resulted in much theorizing about the slow decline and analysis of fertility trends. Looking at fertility trends in real time has led to the identification of countries for whom there has been a failure to decline between two time points, or in fact an increase in fertility between two time points; it has been suggested that these situations indicate a stall in fertility decline. Argentina is commonly cited as an example of a substantial fertility stall (Garenne, 2009); after fertility transition began around the turn of the 19th century and fertility declined steadily, Argentinian fertility stayed around a TFR of 3 from 1947 through 1980 (Pantelides, 1996). Gendell (1985) analyzed the data available to investigate fertility stalls that had been identified in Costa Rica, the Republic of Korea, and Sri Lanka in the 1960s and 1970s, finding that the cause of the stall seemed to differ from country to country. In Costa Rica, the stall identified between 1976 and 1980 was associated with leveling off of marital fertility and contraception use due to the convergence of actual and desired fertility and a weakening of the family planning programs. In Korea, an earlier fertility stall from 1967-1972 was the result of increases in marriage among women age 30-49 years and marital fertility among women under age 30 which offset declines at the same time in marriage among

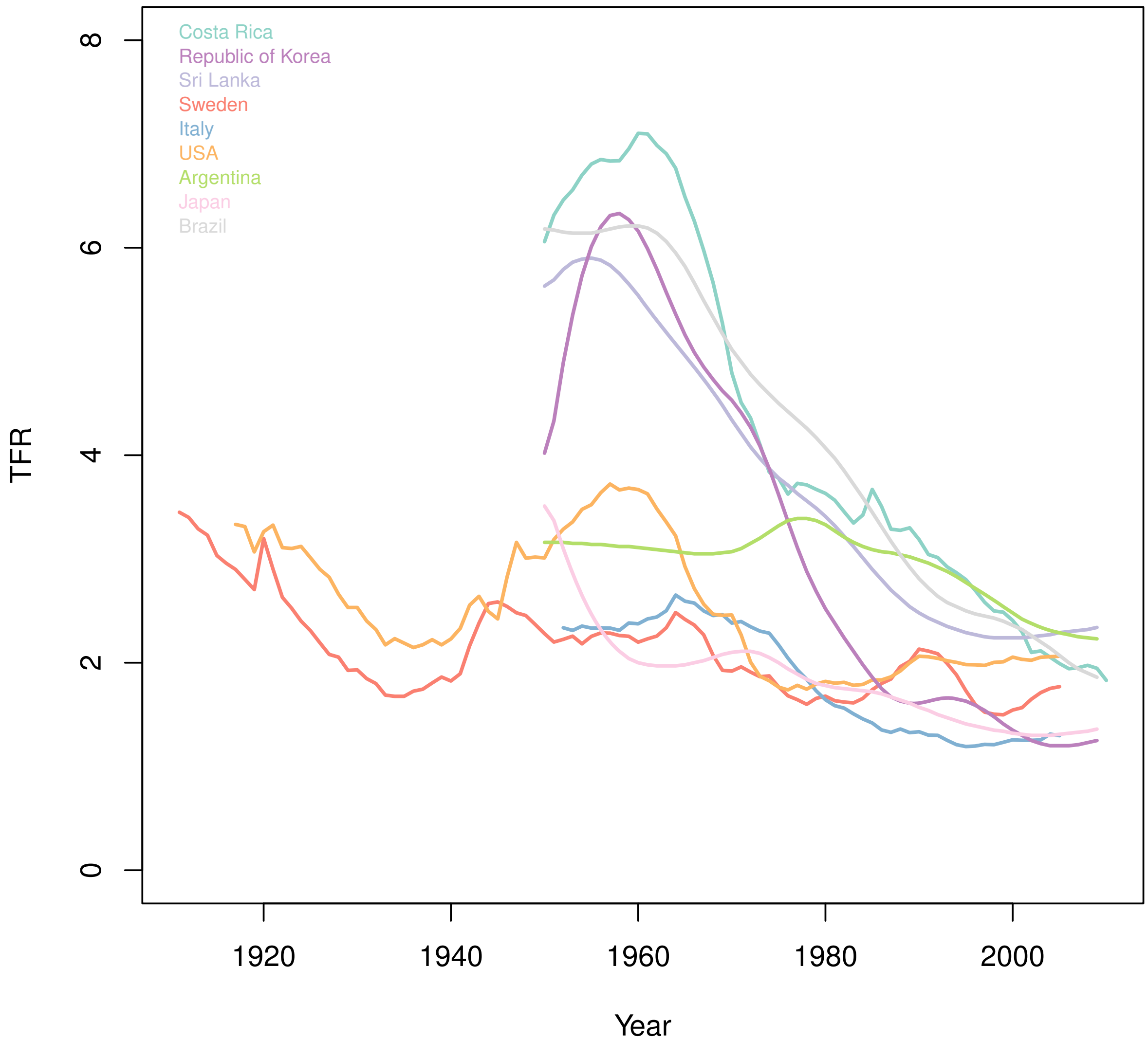

Figure 1.2: Trends in Total Fertility Rate for Selected Countries. Data for Costa Rica, the Republic of Korea, Sri Lanka, Italy, Argentina, Japan and Brazil are from (United Nations, 2013). Data for Sweden and USA are from (Human Fertility Collection, 2015)

women age 15-29 years and marital fertility among women ages 30-49 years. However, the second Korean stall, starting in 1975 and lasting at least until 1980, lacked clear evidence for a cause. Available evidence was not able to explain Sri Lanka's stall from the mid-1970s through 1980 (Gendell, 1985).

Figure 1.2 shows trends in TFR for selected countries, specifically some non-SSA countries identified as having experienced fertility stalls (Argentina, Costa Rica, Korea, Sri Lanka) along side TFR trends for selected countries whose fertility declines are not considered to have stalled (Sweden, Italy, Japan and Brazil) and the USA, whose "Baby Boom" could be considered a stall. Data are from the WPP (United Nations, 2013) except for the USA and Sweden, for which longer data series were available from the Human Fertility Collection (Human Fertility Collection, 2015) that allowed their trends to begin above replacement levels. For Argentina, the 30 year stall can be seen in the flat overall trend as well as a sizable bulge in TFR in the 1980s and 1990s. Similar bulges in the TFR curves can be identified for Sri Lanka, Korea, and Costa Rica. The USA's "Baby Boom" is also evident in these TFR trends. Even for the non-stalling TFR trends, there is still fluctuation, though much of this fluctuation, for the periods shown, occurs around replacement levels. However, data is not available for most of these countries for their periods of higher fertility to examine the fluctuations of their trends (and potential stalls) while these countries were mid-transition.

Gendell (1985)'s criteria for a fertility stall were: 1) a fertility decline must have already begun, having fallen at last one fifth from peak fertility; 2) decline must have been at least 0.15 children per woman per year for at least five years; 3) substantial deceleration in pace of decline (at least halved); and 4) may still show gradually declining fertility. This definition requires a more pronounced decline than some of the definitions of fertility decline onset discussed above and used in areas of high fertility, such as SSA. As a result, researchers focusing on the cases of decline stalls in SSA have altered Gendell's definition, in part to adapt to the data available and also to adapt to the state of high fertility and slower decline in SSA. Bongaarts (2006) defined a stall as no decline between two successive Demographic and Health Surveys (DHS) for countries in mid-transition; a country was considered to be in mid-transition if its TFR was between 2.5 and 5 births per woman at the most recent survey. Moultrie et al. (2008) used slightly different criteria, requiring a significant difference in the rate of fertility decline over two time periods, which were greater than or equal to five but not necessarily the same length. Ideally, in this definition, the slope of the rates should not significantly differ from zero. Moultrie et al. (2008) used Demographic and Health Surveillance Site data from Kwazulu-Natal for this analysis. Garenne (2009), using DHS data, uses a method described as essentially the same as Bongaarts (2006) and those using that definition, but makes use of the cumulative age-specific fertility to age 40 years (adjusted to the traditional TFR by multiplying by 0.9) and analyzing the trends by calendar year, testing the slopes assuming equivalence of period and cohort and defining a stall as periods when the slope changed (significant at the 0.05 level) from negative to zero or positive. Garenne (2011) further refined his definition to require the initial period have a significant, negative slope, a second period with a net zero or positive period, a statistically significant change between the two periods, and, where applicable, a third period with a significant, negative slope. Machiyama (2010), using DHS surveys as well, adapted Gendell's definition to define a stall as occurring for countries whose TFR had already declined by over 20% from the highest observed TFR when the annual pace of fertility decline during an inter-survey period was less than half the pace of the previous inter-survey decline. As seen for the the different operationalizations of the onset of fertility decline, using a different definition of a fertility stall results in different findings.

1.4.1 Fertility Stall Examples, and Debates

Using these similar, but slightly different operationalizations of a stall in the fertility transition, demographers have analyzed trends in SSA fertility and identified which countries appeared to be stalling. Bongaarts (2008), analyzing whether countries had a significant decline in fertility between two surveys, found that 12 of 22 SSA countries appeared to have a stall in fertility decline by this definition (looking at surveys from the late 1990s and early 2000s), while three of the 22 countries were determined to be pre-transition. Bongaarts (2008) found stalls in Cameroon, Côte d'Ivoire, Ethiopia, Ghana, Kenya, Mozambique, Nigeria, Rwanda, Tanzania, Uganda, Zambia and Zimbabwe in SSA, and also Turkey and Guatemala.

Garenne (2009) analyzed six cases of fertility stall: Ghana, from 1998 through 2003; Kenya, from 1997 to 2003; Nigeria, from 1980 (also the onset of fertility decline) through 2005; rural Rwanda, from 1998 through 2005; rural Tanzania, from 1995 through 2004; and urban Madagascar, from 1987 through 1993. He found that a combination of changes in contraceptive use, changes in marriage and birth timing, economic recession, and changes in female labor force participation could explain the stalls in all the countries but Ghana. Ghana's stall could not be explained with the available data. Later analysis, using more recent surveys and continuing to look at urban and rural fertility trends separately, confirmed the stall in urban and rural Kenya from 1994-2002, the urban Ghana stall from 1998-2008, rural stall in Nigeria from 1988-1998, urban Madagascar stall from 1988-1994, rural Madagascar from 1988-1998, urban Rwanda from 1989-1997, rural Rwanda from 1997-2008, urban Senegal from 1995-2002, Tanzania from 1996-2008, and rural Zambia from 1982-1997 (Garenne, 2011). Garenne (2011) tested seven debated stalls using statistical tests described above and found that none of them constituted a stall. Benin, Cameroon and Mozambique were found to have no significant changes since the previous surveys. Ethiopia and Uganda were found to have faster fertility decline in the period that had been determined to be a stall. Côte d'Ivoire and Zimbabwe had a slower decline, but the decline was still negative and statistically different from zero. Garenne (2011) finds that stalls are rare in SSA, finding that only eight of 31 investigated stalls were actually stalls, and five of those were limited either to urban or rural areas and were of short duration (less than 10 years), which were very unlike the 30 year Argentinian stall.

Table 1.1: Comparing Literature on Stalling Fertility

Country/Period	Machiyama (2010)	Bongaarts (2008)	Schoumaker (2009)	Garenne (2011, 2009)
Benin				
2001-06	Stall	Stall	Early Transition	Decline
Cameroon				
1998-04	Decline	Stall	Decline	Decline
Ghana				
1998-03	Decline	Stall	Decline	Stall (urban)
2003-08	Decline	Decline	-	Stall (urban)
Kenya				
1998-03	Stall	Stall	Stall	Stall
Nigeria				
1999-03	Decline	Stall	Early Transition	Decline
2003-08	Decline	Stall	-	Decline
Rwanda				
2000-05	Stall	Stall	Stall (rural)	
2005-07/8	-	Decline	-	Stall (rural)
Tanzania				
1999-04	Early transition	Stall	Decline	Stall
Uganda				
1995-06	Early transition	Stall	Pre-transition	Decline
Zambia				
1996-01/2	Decline	Stall	Decline	Stall (rural 1997)
2001/2-08	Stall	Stall	-	Decline

Adapted from Machiyama (2010)

Schoumaker (2009)'s position is that a possible explanation for the fertility stalls is that they are actually spurious, resulting from data quality issues. Using published TFR data from

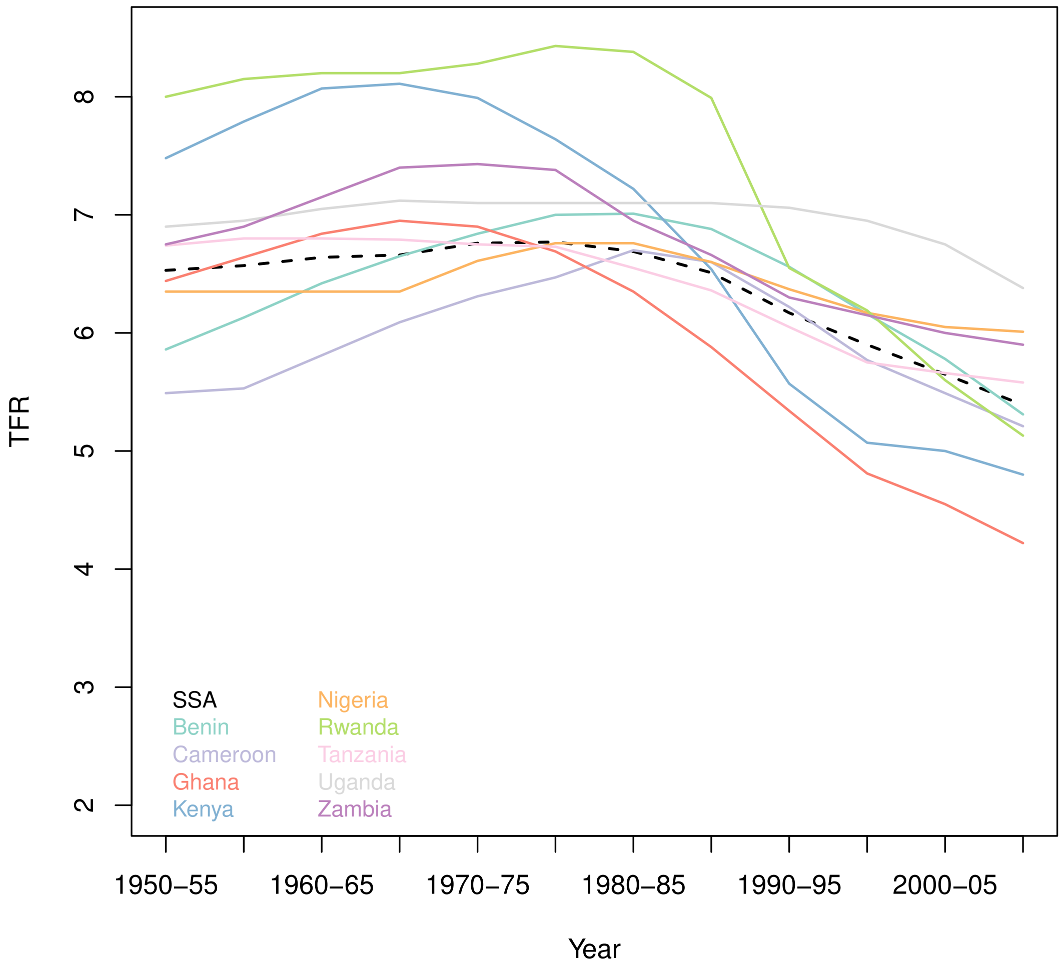

Figure 1.3: Trends in Total Fertility Rate for SSA countries identified as stalling. Data are from (United Nations, 2013).

the DHS from 24 countries from 71 surveys, nine stalls were identified: Benin, Cameroon, Ghana, Guinea, Kenya, Mozambique, Nigeria, Rwanda, and Tanzania (though four countries were identified as having no discernible fertility decline, or being pre-transition: Chad, Mali, Niger, and Uganda). To examine whether the trends were spurious, TFR was regressed on proximate determinants and socioeconomic variables that should predict TFR to evaluate whether the observed TFR was similar to expected TFR and found that the patterns of residuals from these models suggest that the supposed stalls or fertility reversals were likely reflecting underestimation of fertility in the earlier survey. Retrospective TFRs were also constructed from birth histories, and it was found that late 1990s fertility estimates were lower than the reconstructed TFRs. The most extreme case was Nigeria's 1999 DHS, which was also excluded from Bongaarts (2008) analysis due to concerns about data quality; Nigeria showed a dramatic decline in TFR in the late 1990s, but through the retrospective TFR reconstruction analysis it appears that there were many omissions of births in the three years prior to the survey. Excluding those years, the decline is much less pronounced through the 1990s and no reversal in fertility decline seems to have occurred; similar problems were identified for Benin, Cameroon, Guinea, Mozambique and Rwanda. Kenya, Ghana, and Tanzania did not have obvious birth omissions, though, did have some discrepancies of TFR estimates between consecutive surveys. Schoumaker (2009) identified several data quality issues contributing to spurious fertility stalls: sample implementation issues, related to the composition across surveys that may affect groups; and underreporting of births during a specific time period, usually to avoid the longer questionnaire for recent births (within five years of the survey) (Schoumaker, 2009). The only stall that Schoumaker (2009) confirms is Kenya's stall in the late 1990s.

Machiyama (2010) summarizes the differences between Bongaarts (2008), Garenne (2009), Schoumaker (2009), and Sneeringer et al. (2009) in a table, which is updated here (Table 1.1) to include the results from Garenne (2011). Machiyama (2010) analyzed 33 DHS surveys from nine countries, looking at fertility trends over 15 years, to examine their supposed stalls. Ghana was found to have near constant decline that was much more rapid than the decline seen in other West African countries, and the 1998-2003 observed stall was likely to be spurious. Cameroon saw a decline, but that decline was much more rapid in the urban areas. Machiyama (2010) found evidence of decline in Nigeria but stipulated that the data was of such poor quality that long term trends were difficult to interpret. Tanzania and Uganda were found to be early in their transition, with Uganda having a clear urban decline even though the published urban TFRs indicate a stall though Tanzania showed some indication of an upward fertility trend. Machiyama (2010) found evidence of stalls in Kenya (1998-03); Benin (2001-06), particularly in urban areas; Rwanda in 2000-05, and Zambia from 2001/2-08, though found evidence of urban decline during this period. The trends in TFR for each of these countries are shown in Figure 1.3 along side the overall trend for the SSA region.

Bongaarts and Casterline (2013) estimated that for nine of 20 SSA countries where fertility had declined by at least 10% earlier the estimated TFR had been unchanged or increased between the two most recent DHS surveys, but argued this could actually be due to measurement error. Potential, documented sources of measurement error include age displacement of children, specifically when interviewers back date the ages of recent children to avoid responding to longer questionnaires and subsequently underestimate recent fertility; data quality may be compromised as the questionnaires become longer; and sampling bias resulting from sociodemographic groups that have higher or lower fertility than the general population are over-represented in the sample fertility estimates can be biased (Machiyama, 2010).

The one case of stalling that is universally agreed upon is that of Kenya from 1998 through 2003. Machiyama (2010) found good agreement across surveys suggesting a real stall, with decelerated fertility decline starting by 1996 and the partial TFR leveling off at 4.5. Kenya's TFR had declined to 4.7 in 1998 from a peak of 8.1 in 1977-78, at which point it stalled, with the decline interrupted across all age groups (Westoff and Cross, 2006). Westoff and Cross (2006) found that the stall occurred throughout the country, except Central Province, and that the stall was most pronounced for the least educated women, with fertility still declining for women with secondary or higher education. Contraceptive prevalence through this period also stalled, and modern contraception use was flat in the 10 years prior to the 2003 survey. Though, use of injectable contraception was increasing while other forms of modern contraception were declining. Overall, there was an increase in the number of desired children over the stalling period, particularly among the least educated and Muslim women, who also saw the most dramatic reversal in fertility trends. However, these women do not make up enough of the population to explain the stall completely. Teenage pregnancy was also on the rise, particularly in Nairobi and possibly Nyanza. Overall, Westoff and Cross (2006) felt that the stall was largely explained by the stalling of contraception use and increase in desired family size and the more general social and economic changes in Kenya going on at the time, as well as likely effects of the Kenyan government and international support of family planning programs. Garenne (2009) also felt that the lower contraceptive use and difficult economic situation were to blame for the stall, combined with rising child mortality and minimal change in the age at marriage and a slightly earlier age at first birth.

1.4.2 Hypothesized Causes of Fertility Stalls

While there has been a fair amount of work dedicated to analyzing the fertility stalls seen in SSA in the 1990s and 2000s, there is no consensus on the causes (Schoumaker, 2009; Westoff and Cross, 2006). Generally, the same explanations used for fertility decline are applied to explaining a stall in this decline. Proximate determinants of fertility are widely used to explain stalls, in particular contraception use and desired family size, though these explanations then demand an explanation for the stalling in contraception use or the increase in desired family size. Economic explanations are also common, relying on the relationship between fertility decline's onset and pace with the level of socioeconomic development. Relatedly, urbanization, female education, and female empowerment are used to explain fertility stalls, as approximate measurements of development level and also as their own explanation. Mortality, a key component of demographic transition theory, also is hypothesized to be a cause of stalling, through increased infant or child mortality, or through high HIV prevalence. This section presents a summary of evidence for these explanations of fertility stalls. However, from the earlier sections, it is clear that there is no consensus on whether the contexts for which this evidence draws from are actual stalls. We can, however, consider this evidence as at least related to apparent stalls or at minimum a slowing pace of fertility decline. If nothing else, a "stall" can be considered to be a fertility decline that is not behaving the way demographers and global health experts would expect or prefer, i.e. it is declining too slowly.

Most directly, desired fertility and contraception use are theorized to be causing fertility stalls, with varying evidence. Bongaarts (2006) argued that a stall is typically accompanied by near stalling of demand for, use of and unmet need for contraception. Ezeh et al. (2009) also found a that stalling fertility was associated with a stall in contraception demand when looking at East African countries. However, Garenne (2009) found that contraception use increased in Ghana and Tanzania during their stalls, while contraception use in Kenya, Rwanda, and Nigeria stalled. Bongaarts (2006) found little or no change in wanted or unwanted fertility during the stalls. Though in Kenya, Westoff and Cross (2006) found a decline in women who wanted to limit their family size. Unmet need for family planning declined and then was flat. During the stall, the proportion of women who wanted no more children declined and the total wanted fertility rate plateaued, indicating a large increase in unwanted pregnancies. The stall in contraception was most pronounced among women with the least education (Westoff and Cross, 2006). Bongaarts (2006) also found decline or plateau in the age at marriage was associated with fertility stall. Gendell (1985) linked Costa Rica's fertility stall to stalled contraception use.

Economic development, as linked to socioeconomic development theories of fertility transition, is also commonly hypothesized as an explanation for fertility stall. If economic development contributes to the start and the pace of fertility decline, then reasonably, stagnation or reversal in development may be associated with fertility stall. Effort has been made to tease out the relationship between socioeconomic development and fertility decline, particularly in light of the slower fertility decline experienced in SSA than that of Latin America and Asia. Bongaarts and Watkins (1996) found that over time there had been a clear reduction in the level of socioeconomic development at the onset of fertility decline, and that while there was no correlation between the rate of change in development indicators and the pace of fertility decline, there was a strong correlation between the pace of decline and level of development at onset. Extrapolating from this finding, as most SSA countries began the demographic transition at lower levels of socioeconomic development (by either gross domestic product (GDP) or the Human Development Index (HDI)), it is easy to theorize that disruptions or stagnation in socioeconomic development could be a potential cause of a fertility stall. Casterline (2001) found that more rapid improvements in economic development were associated with a more rapid decline in fertility. Bongaarts (2006) found a correlation between development progress and TFR, looking at GDP and TFR for 38 countries (using DHS data), and GDP was stalled as well as fertility in Ghana and Kenya. Shapiro and Gebreselassie (2009), however, using DHS data from the 1980s found that fertility decline was slower when economic growth was more rapid. Bryant (2007) concedes that development indicators are not a direct measure of the sophisticated conceptualizations of how fertility is related to socioeconomic development, though finds, along the lines of Bongaarts (2002) that while the onset of fertility decline and socioeconomic indicators are not well correlated, once the demographic transition is underway they are. In Brazil, the spatio-temporal pattern of fertility change was found to be largely attributable to patterns of economic development (Schmertmann et al., 2008). Of the stalls that Garenne (2009) confirmed, Rwanda and Ghana were experiencing improvements in income, while Kenya, Madagascar, and Tanzania were not. Garenne (2009) looked at GDP-PPP in constant USD, educational attainment, labor force participation and the DHS wealth index to assess income, rather than relying solely on GDP, and notes that from 1950-75, GDP increased while fertility increased in SSA and that GDP was not correlated with trends in the wealth index or poverty from DHS measures. Garenne (2009) concludes, in fact, that "the diversity of situations makes any generalization impossible" in regards to the relationship between economic development and SSA fertility stalls. In thinking about the role of socioeconomic development in fertility decline, it is important to consider the well-documented problems with measuring economic development in SSA and the data quality issues associated with GDP data (see Jerven, 2013).

Urbanization is frequently associated with lower fertility, explained in part through the effects of migration (including selection and spousal separation) and the effects of modernization and Westernization associated with urban living. Fertility differs greatly between urban and rural areas in SSA. Garenne (2009, 2011) demonstrated in his analyses that fertility stalls may be limited to one area or another, and not consistently rural or urban, while Shapiro and Gebreselassie (2009) found living in an urban area was associated with lower fertility across countries experiencing stalls or low fertility decline. Analyzing the urban-rural gaps in fertility in the proposed stalling countries, Machiyama (2010) found that over 15 years the gap between urban and rural TFR was widening for Benin, Cameroon, Nigeria, Tanzania and Zambia, while the gap in Ghana and Uganda widened until 2000 after which it was constant and the gap in Kenya was nearly constant while Rwanda's gap narrowed. During the stalls Garenne (2009) identified, urbanization continued.

Education is commonly analyzed in association with fertility decline in the developing world, and low levels of education among women has been linked to fertility stalls. Fertility differentials across education are persistent over time and place, and Bongaarts (2003) found that low levels of schooling among married women was a likely contributor to stalling in Egypt and Bangladesh. In East Africa, Ezeh et al. (2009) found an association between education level and fertility stalls at the sub-national level, and Shapiro and Gebreselassie (2009) also found some support for an effect of education levels on fertility in stalling countries. In Kenya, the most pronounced stall in fertility was among the least educated, and, in fact, women with secondary or higher education actually continued to experience decline (Westoff and Cross, 2006). Shapiro (2012), using DHS data for 28 SSA countries with surveys since 2000, found a broad negative correlation between women's education and fertility for the world and also for SSA. Countries with an increasing proportion of women with higher levels of education saw faster fertility decline, and at the level of the individual woman, a woman was less likely to have more children the higher her level of education, with the effect increasing with increased education.

Female empowerment is often discussed, generally in tandem with female education, as a crucial factor contributing to fertility decline. Often, women's educational attainment is used as a proxy measure for female empowerment. McDonald (2000) suggests that understanding gender relations that are present during the decline are important for understanding pace of decline, and by extension fertility stalls. High fertility is socially determined and the transition from high to low fertility is accompanied by an increase in gender equity within the family, which has a major effect on women's lives (McDonald, 2000). However, research investigating the connection between gender equity and fertility stalls has been limited, and when done limited to the proxy measures, such as education or labor force participation. Garenne (2009) found that increasing female labor force participation was the only socioeconomic indicator that differed between his cases of fertility stalling and the controls; women's labor force participation increased for the cases during their stalls.

The effectiveness, or ineffectiveness, of family planning is frequently hypothesized to contribute to declines in fertility stalls, specifically that lack of access to contraception, lack of political will for family planning, and inadequate family planning education lead to higher fertility and a stall. McDonald (2000) argues that because family planning programs have been forced to work within the family in many developing countries, family planning efforts have inadvertently led to improved status of women within the family and thus family planning programs contribute to fertility decline through fostering female empowerment. However, family planning program impact is difficult measure. Bongaarts (2006) did not find any association between stalling and the level of family planning program effort, though Ezeh et al. (2009) did find an association at the sub-national level between family planning program and contraception access and East African fertility stalls. Gendell (1985) found evidence of association between weakened family planning programming with stalls in both Korea and Costa Rica.

Integral to demographic transition theory is the idea that reductions in mortality, particularly infant and child mortality, lead to reduction in fertility (Notestein, 1945), and, accordingly, rising or plateaued infant and child mortality has been hypothesized as a contributing factor to fertility stall in SSA. While the worldwide convergence in mortality has been remarkable, with increasing overlap in mortality between developed and developing regions, in SSA in particular there is a sizable population that has only seen modest improvements in mortality (Wilson, 2001). Casterline (2001) found that more rapid declines in mortality brought about more rapid declines in fertility, and Shapiro (2012) found that child mortality reductions were associated with fertility decline. Shapiro and Gebreselassie (2009) examined the relationship between infant and child mortality and fertility stalls, with non-definitive results. In Kenya, Magadi and Agwanda (2010) found that child mortality or fetal loss was associated with increased fertility at the individual level. Evidence exists for the connection between individual women's fertility choices and their experience of child loss, in addition to some population level correlation between mortality improvement and fertility decline. However, attempts to analyze the role of changes in infant and child mortality on fertility stalls have been few and inconclusive.

In countries with high prevalence of HIV, HIV has altered the population and its dynamics profoundly, with massive mortality and morbidity, which has impacted fertility both through altering population composition as well as affecting both reproductive behavior and biological reproduction. However, research is far from conclusive about how high HIV prevalence may be affecting fertility and whether it may be a factor contributing to fertility stall. HIV can be associated with lower fertility due to reduced coital frequency and sexually transmitted infection co-infection associated with pelvic inflammatory disease and increased fetal loss. HIV is hypothesized to influence many of the proximate determinants of fertility, both to increase and decrease fertility. HIV may reduce fertility by delaying onset of sexual relations and age at first union; reducing premarital sex and remarriage; increasing marriage dissolution and spousal separation; increasing condom use; increasing postpartum ammenorhea; reducing pregnancy rates and increase fetal loss; increasing STI prevalence; and reducing frequency of intercourse and reduce sperm production. Alternatively, HIV may be associated with higher fertility through reduced breastfeeding; reduced postpartum abstinence, and increased infant mortality resulting in child replacement. HIV may reduce desired fertility (Magadi and Agwanda, 2010). Magadi and Agwanda (2010) argued that though HIV contributed to Kenya's stall, it was not the sole cause, and, using the 2003 Kenya DHS data, the authors did not find a a significant relationship between HIV status and desired family size but did find a significant relationship between higher community HIV awareness and desire to limit family size. HIV-postive women had a about a 40% lower odds of a recent birth than HIV-negative women, but there was no evidence of an association between community level HIV prevalence and fertility (Magadi and Agwanda, 2010). HIV may serve to increase fertility, as perceived HIV risk may shift contraceptive method mix to less effective methods, condoms, as part of dual-use strategies, and roll-out of prevention of mother-to-child transmission (PMTCT) of HIV has enabled HIV positive women to have HIV-free children in more recent years (Moultrie et al., 2008). Juhn et al. (2013), however, found that HIV prevalence in a community has a somewhat depressing effect on fertility, though this is not analyzed in consideration of pre-HIV fertility trends. Gregson et al. (2002) argue that HIV infection is facilitated by increased urbanization, secularization, and economic development and that the effect of the HIV epidemic on fertility is in part determined by the point in the transition when the epidemic hits. The authors argue that there is some increased fertility as a response to increased mortality, both acting as insurance and replacement. In a population-based cohort of over 3500 women in rural southwest Uganda followed for over seven years, fertility rates were lower for HIV-postive women except at the lowest age groups (15-19 years) (Carpenter et al., 1997). For Kenya, HIV may have contributed to the stall by halting the reduction in desired family size due to increased child mortality (Westoff and Cross, 2006). Garenne (2011) indicated that high HIV prevalence could lead to overestimation of fertility, since fertility is measured retrospectively and HIV-positive women who died, and have lower total fertility, are missing from the data. In theory, this could contribute to apparent fertility stalls, though Garenne (2011) found no correlation between fertility and either HIV prevalence or HIV mortality.

Across the varying operationalizations of a fertility stall and the slow or stagnant decline seen in many countries across SSA at different time periods, Kenya from the late 1990s through early 2000s is the only fertility stall for which there is unanimous agreement amongst demographers. For all other stalls proposed, there is at least one other researcher who disputes that a stall occurred there at all. Unsurprisingly, with demographers unable to determine where and when a stall has happened, compared to just slow pace of decline, or in fact in some cases fairly substantial decline, there is also no consensus on causes. Evidence can be found for a variety of potential factors that may create or contribute to causing a stall, generally related to the proximate determinants of fertility or connected to the theoretical causes of fertility transition, but has not proven consistent across stalls in different countries, even when identified with the same stalling criteria. Gendell (1985) suggested it was unlikely stalls in different countries would have the same causes. These inconsistencies both in the determination or identification of stalls as well as their underlying causes suggest that in fact fertility trends in SSA through the turn of the 21st century do not conform well to expected fertility trends under demographic transition theory and that naming these non-conforming trends "stalls" may not be providing much further explanation of SSA fertility transition, though stalls do provide a way to categorize trends that are surprising under demographic transition theory and the assumption that by the late 1990s most of SSA had begun fertility decline and fertility transition.

1.5 Global Fertility Convergence

Meanwhile, demographers have been analyzing global fertility trends looking at whether or not global fertility rates have been becoming more similar. These analyses have been largely focused on understanding lowest-low fertility in post-transition societies, but the insight they provide for this study is to highlight how different SSA fertility decline has been. Myrskylä et al. (2009) found a negative relationship between development and fertility in a cross country analysis of TFR and HDI, but with a J-shape, indicating that at the highest levels of development there was a reversal in the relationship, with an increase in fertility at those highest levels of development. However, analysis with a revised measure of HDI found that their comparable development threshold was no longer significant (Harttgen and Vollmer, 2013). These findings indicate that even at higher levels of development, this relationship between fertility and socioeconomic development is not well understood and also the complexity of using socioeconomic development measurements, even for developed countries.

Strulik and Vollmer (2010) used UN WPP data from 2008 to analyze TFR convergence, testing for β-convergence (countries of initially high fertility experience stronger decline than countries of initially low fertility) and σ-convergence (cross-sectional dispersion declines over time). For the high fertility group of countries, neither type of convergence was found and instead these TFRs seemed to get further apart. Strulik and Vollmer (2010) interpret these findings to mean there is some sort of high fertility equilibrium at work, determined by country-specific factors. Meanwhile, once a country enters the low fertility group, both types of convergence occur (Strulik and Vollmer, 2010). Wilson (2001) also uses the UN WPP data, though states concern about the homogenizing effect which may omit effects like HIV in the 1990s in South Africa. He finds substantial convergence of TFRs, though there is still a considerable tail of high fertility population (Wilson, 2001). Dorius (2008) builds on Wilson (2001)'s work and finds that convergence of TFRs only started recently, but that without SSA cross-national convergence would have started decades earlier, indicating that SSA fertility has remained the outlier in global fertility trends. Inequality in fertility increased monotonically until 1995, driven by SSA (Dorius, 2008).

1.6 African Exceptionalism

An alternative theory to explain the slow decline in SSA fertility is that African fertility decline is fundamentally different from fertility decline elsewhere, that the transition in SSA will not look the same and is not the same as the transition has been in the West, Latin America and Asia. Caldwell and Caldwell (1987) introduce the idea, attributing the reasons for slow decline largely to religion, arguing that in Africa "lineage-based systems are so coherent that they will offer greater resistance to the successes of family planning programs than has been encountered elsewhere" (Caldwell and Caldwell, 1987). In fact, Caldwell and Caldwell (1987) argue that fertility in SSA is high in spite of severe constraints to fertility in many African contexts, such as the taboo on pre-marital fertility, lengthy postpartum abstinence, terminal female abstinence once women become grandmothers. These constraints are overcome by polygyny, widow remarriage, and an emphasis on the desire for conception (Caldwell and Caldwell, 1987). Caldwell et al. (1992) concede that fertility decline has begun in SSA, since the 1990 DHS results, specifically in Botswana, Zimbabwe and Kenya, followed by Nigeria. Botswana, Zimbabwe, and Kenya had the lowest infant mortality rates in SSA and relatively high levels of female education as well as high contraceptive prevalence. According to Caldwell et al. (1992), African fertility is high because SSA remains much less developed than South Asia; the importance of ancestry and descent lead to economic returns for high fertility; polygyny, bride wealth and reproductive decision-making remove the decision making (done by men) from the economic burden, carried by women; communal land distribution and labor-intensive production meant more people, more economic benefit; and there is nearly no family planning, largely due to a lack of political will. These factors will also make the SSA transition different from the Asian transition; there are major differences in constraints on premarital and extramarital sexuality, differences in marital stability, and different emphases on the need and reasons for birth spacing. In SSA there is extensive male and female premarital sex, which is a potential source for contraception uptake. There is also a strong demand for spacing due to the traditionally long birth intervals being shortened as traditional postpartum abstinence declines, which provides another source for contraception demand. Additionally, there may be demand for contraception in later years as an alternative to terminal abstinence. Fundamentally, Caldwell et al. (1992) argue the SSA decline will be different because contraception use and fertility decline will be similar across all ages, compared to declines elsewhere in which decline began at age 25 years and older, increasing with age with the largest decline after age 40. The SSA declines will be characterized by fertility declines at all ages, both within and outside of marriage (Caldwell et al., 1992).

Moultrie et al. (2012) build on this theory using DHS data from 24 SSA countries to look at birth interval dynamics from 1986 through 2010. Their analysis showed a wide variety in birth interval trajectories, but all have been widening since the 1970s, with the widest birth intervals in South Africa and Namibia (about four years). Birth intervals have widened in most countries with lower fertility and higher contraceptive prevalence, but the trend of interval lengthening has been consistent and largely independent of the woman's age and parity. While historical data related to birth intervals is not immediately available to determine whether this effect is different from other transitions, the finding that intervals are lengthening at all ages and parities lends support to the Caldwell et al. (1992) argument that the decline will occur at all ages rather than at later ages first (Moultrie et al., 2012).

1.7 Conclusion

To understand SSA fertility patterns, we need to think about them as part of global fertility patterns. Determinants of fertility are not different in SSA, whether perceived of from a proximate determinants framework or a broader framework analyzing mortality and development's effects on fertility. This dissertation will analyze fertility within a global context, quantifying the differences between regions and exploring how commonly hypothesized determinants of fertility change are relevant for understanding fertility change across time and space in a way that directly incorporates the empirical global evidence, in the theoretical explanation, with a focus on understanding how SSA fits into the global context.

Chapter 2

MALE AND FEMALE STERILITY IN ZAMBIA

2.1 Introduction

[1]Population measures of fertility and sterility are usually constructed from birth histories from women and thus limited to the population of women rather than the general population. However, fertility or its absence, are conditions experienced by a couple, and the causes of sterility can be related to the male partner, female partner or both partners. Medical studies (Folkvord et al., 2005) and anthropological studies (Gerrits, 1997; Dyer et al., 2004) provide direct evidence of male sterility in multiple locations in Africa. Determining whether sterility is due to male or female disorders is often difficult, and generally less is known about the prevalence of male sterility (McFalls Jr and McFalls, 1983). (McFalls Jr and McFalls, 1983) estimate between 20 and 60% of couple infertility across populations is accounted for in whole or in part by male sterility. As sterility, primary or secondary, is potentially related to either the male or female member of the couple, estimating male sterility can provide a more complete picture of population-level sterility than female estimates alone.

This analysis aims to describe the sterility of Gwembe Tonga men by applying Larsen and Menken (1989, 1991)'s subsequently infertile measure using incomplete birth histories. Data for the Gwembe Tonga provide a unique opportunity to estimate male sterility because male birth histories were recorded. Juxtaposed with measurement of sterility for the women in the same population, this analysis seeks to describe sterility among the entire Gwembe Tonga population. Measures of female sterility from Zambia Demographic and Health Surveys

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(ZDHS) data from 1992, 1996, 2001-02, and 2007 are also presented to provide national context for the Gwembe Tonga analysis.

2.2 Background

2.2.1 Sterility in Africa

Fertility rates vary widely across and within countries in sub-Saharan Africa (for example Bongaarts et al., 1984), and evidence from demographic measurement of sterility has shown wide variation across the continent as well. Earlier studies have tried to measure the inability to have a live birth, and we use the word sterility for any measures of the inability to have a live birth. Larsen (2000) found relatively low rates of primary sterility but high rates of secondary sterility. Rates of secondary sterility ranged from less than 10% to 25% for women age 25-44 (Larsen, 2000). Other researchers have found similar variation (Ericksen and Brunette, 1996). Frank (1983) found great variance in rates of primary sterility by country and also by ethnic group in Africa. Bongaarts et al. (1984) cite substantial variation in measured primary sterility across Africa, varying from 3% to 20% or higher, and noted substantial variation within countries. Similarly, Jensen (1995) found substantial differences in secondary sterility rates in two Kenyan communities.

2.2.2 Zambia and the Gwembe Tonga

Zambia is a landlocked country in southern Africa with an estimated mid-year 2013 population of over 14 million. Life expectancy remains among the lowest in the world (52 years) with maternal mortality and infant mortality rates among the highest Fertility rates in Zambia are high; total fertility was estimated at 6.2 in 2007. Contraceptive use has increased from 15% of women in 1992 to 41% in 2007, 33% using a modern method in 2007 (Central Statistical Office and Inc, 2009). Relatively little information about sterility in Zambia has been published. Using parity progression ratios to analyze Zambian censuses, Sunil and Pillai

(2002) found that the proportion of women who were sterile increased from 0.12 in 1980 to 0.15 in 1990, with evidence of regional variation. The authors estimated that sterility rates in Southern Province, where the Gwembe Tonga live, increased from 0.11 to 0.14 between 1980 and 1990 (Sunil and Pillai, 2002).

This analysis estimates sterility among the Gwembe Tonga using a data set collected from 1956-1995 (Clark, 2001). The Gwembe Tonga traditionally lived in the valley of the Zambezi River but many were forced to relocate in the late 1950s to make way for the Kariba Dam and its reservoir. Gwembe Tonga women marry early (mean age of 16.5 years) and nearly universally (97% married by age 45). Gwembe Tonga fertility rates have remained high (total fertility of 6) through the 1980s (Clark et al., 1995). In the late 1950s as many as 40% of men practiced polygyny (Colson, 1971). Polygyny is still practiced, though less common (Clark, 2001). Marriage and fertility practices are similar for the Gwembe Tonga and ZDHS national samples (Tables 2.1 and 2.2).

Table 2.1: Population size, marital and birth history descriptive statistics for women in the Gwembe Tonga and Zambia DHS (1992, 1996, 2001-02, and 2007) datasets.

	Gwembe Tonga	1992 ZDHS	1996 ZDHS	2001-02 ZDHS	2007 ZDHS
Individuals age 20 and over	2206	4800	5637	5487	5269
Ever married	1768	4516	5219	5063	4747
Married individuals*	1405	3615	4071	3416	2264
Mean age first marriage (SE)	19.9 (0.16)	17.2 (0.05)	17.5 (0.05)	17.7 (0.05)	18.1 (0.05)
Married more than once (%)	143 (8%)	1186 (26%)	1346 (26%)	1240 (25%)	1009 (21%)
Mean age at first birth (SE)	20.4 (0.07)	18.1 (0.05)	18.3 (0.04)	18.3 (0.04)	18.5 (0.04)
Mean birth interval (SE)	2.7 (0.02)	2.8 (0.97)	2.8 (1.04)	2.9 (1.01)	3.0 (1.02)
Last closed birth interval $\geq$ 5 years	5.6%	21.2%	23.5%	21.0%	21.5%
Mean number of live births (SE)	4.1 (0.08)	4.6 (0.04)	4.5 (0.04)	4.4 (0.04)	4.3 (0.04)
Mean number of living children (SE)	3.1 (0.06)	3.8 (0.4)	3.6 (0.03)	3.7 (0.03)	3.6 (0.03)
Percent Childless**	8.10%	2.41%	2.73%	2.74%	2.53%

*These are married individuals included in the analysis. For the Gwembe Tonga, these are individuals continuously married for 5 years preceding each observation included in analysis; for the ZDHS, these are women who married at least 5 years prior to the observation and were still married at the time of the survey.

**Percent childless was estimated for those married at least 7 years before last observation using Larsen's method (Larsen, 2000).

Table 2.2: Population size, marital and birth history descriptive statistics for men in the Gwembe Tonga and Zambia DHS* (1996, 2001-02, and 2007) datasets.

	Gwembe Tonga	1996 ZDHS	2001-02 ZDHS	2007 ZDHS
Individuals aged 20 and over	1900	1307	1591	4829
Ever married	1258	1041	1341	3910
Married individuals**	1021	Not included in analysis		
Mean age at first marriage (SE)	25.6 (0.24)	22.8 (0.13)	22.6 (0.11)	22.9 (0.07)
Married more than once (%)	1083 (84%)	349 (34%)	524 (39%)	994 (27%)
More than 1 wife	337 (27%)	93 (10%)	122 (10%)	284 (8%)
Percent of polygynists with exactly 2 wives	68%	94%	84%	91%
Mean age at first birth (SE)	25.0 (0.18)	Not available		
Mean birth interval (SE)	2.4 (0.02)	Not available		
Last closed birth interval ≥ 5 years	4.2%	Not available		
Mean number of live births (SE)	4.5 (0.16)	4.8 (0.12)	5.0 (0.11)	4.7 (0.05)
Mean number of living children (SE)	3.3 (0.11)	3.9 (0.10)	4.1 (0.09)	4.0 (0.05)
Percent childless***	17.10%	Not available		

*The 1992 ZDHS did not contain a male sample.

**These are married individuals included in the analysis. For the Gwembe Tonga, these are individuals continuously married for 5 years preceding each observation included in analysis; for the ZDHS, these are women who married at least 5 years prior to the observation and were still married at the time of the survey.

***Percent childless was estimated for those married at least 7 years before last observation using Larsen's method (Larsen, 2000).

2.3 Data

Data for the Gwembe Tonga come from the Gwembe Tonga Research Project, begun by Elizabeth Colson and Thayer Scudder in 1956, with yearly data on unions and births through 1995. Four villages are included in the dataset, and the sample includes all the inhabitants of these villages as well as individuals born to or marrying members of the sample or migrating into the villages. Individuals left the sample through death or by moving away (Clark, 2001). These data are ideal for estimating sterility for men because birth histories are separately available for both men and women. To compare sterility estimates for the Gwembe Tonga with Zambia, Demographic and Health Survey data from 1992 (ZDHS 1992), 1996 (ZDHS 1996), 2001-02 (ZDHS 2001-02) and 2007 (ZDHS 2007) are used. Analysis was restricted to currently married individuals at least age 20 years in the ZDHS because divorce dates were not available and periods of marriage and separation could not be identified in those data. All ever-married individuals, men and women, over age 20 years were included from the Gwembe Tonga data, with analysis limited to observations for which the individual had been married for five consecutive years prior to the observation; years when an individual was separated after the first union or the first years of any union were excluded from analysis to ensure exposure to pregnancy, following Larsen and Menken (1989, 1991). Analysis was limited to individuals age 20 or over following the recommendation of Larsen and Menken (1991), based on their sensitivity analysis that found a substantial difference in true and assigned age at sterility for ages below 20 years.

The period covered by this data was tumultuous for the Gwembe Tonga and evidence shows that social organization and behaviors changed over this period in ways that may impact fertility desires and practices and fecundity (Clark et al., 1995). For analysis, time periods were selected to capture key events for the Gwembe Tonga and Zambia though consultation with the Gwembe Tonga Research Project (Thayer Scudder, personal communication). Period one, 1950 to 1963, covers a brief period before the Kariba dam project and relocation and resettlement. Period two, 1964 to 1972, covers nine years of relative stability and economic growth. 1973 to 1981, period three, saw dramatic deterioration of the Zambian political economy and the war for Zimbabwe Independence, which disrupted economic and social services for the Gwembe Tonga. In period four, 1982 to 1990, health conditions deteriorated and HIV/AIDS became a large problem in Zambia. During period five, 1991 to 1999, health problems and the burden of HIV/AIDS continued as the economy stagnated and there were a series of floods and droughts. In the final period, 2000 to 2008, the economy improved and access to HIV care and treatment improved. No data used for the Gwembe Tonga fell in the last period, though some of this period is captured in the 2001-02 and 2007 ZDHS data. Later ZDHS datasets did not have observations for the earliest time periods. Over 50% of observations in the 2007 ZDHS were in the last time period and for the 2007 ZDHS time periods were collapsed to 1973-1999 and 2000-07 to accommodate sparseness in certain age and time period categories.

2.4 Methods

This analysis uses Larsen and Menken (1989, 1991) method for measuring population sterility, defined as the inability to have a live birth, to estimate sterility of Gwembe Tonga men and women. The measure is implemented in the same manner for both men and women. This analysis is the first that the authors are aware of that estimates male sterility at the population level using a measure that has been exclusively used for women but can be applied here because of the availability of male birth history data. Larsen and Menkens *subsequently infertile* indicator measures the proportion of individuals who are *subsequently infertile* after a certain age using incomplete birth histories. For this measure, infertility is defined as an individual being observed for a specified time T without having a live birth, despite being sexually active and not using contraception. This method estimates the proportion of individuals who become sterile between age a and age $a + T$, at some age $a*$. An indicator for sterility was assigned for each person-year. For person-years that meet the criteria for inclusion in the dataset (age 20 years or older, married at least five years earlier, followed for the following five years), an individual was sterile if, in the last, open birth interval the individual did not have a live birth during any of the following five years.

T is generally five years, as birth intervals are usually no longer than five years. However, women with open birth intervals longer than five years will be categorized as infertile using this method, risking overestimation in populations with wider than average birth intervals. Larsen and Menken (1991) argue that women who had subsequent births outside of the interval were likely subfecund, and in both the male and female Gwembe Tonga data, as well as all ZDHS datasets, average birth intervals were below five years (Tables 2.1 and 2.2). However while few last, closed birth intervals were longer than five years for the Gwembe Tonga women (5.6%) or men (4.2%), more that 20% of women in each ZDHS dataset had last, closed birth intervals longer than five years (Tables 2.1 and 2.2). It is possible the larger portion of ZDHS last, closed birth intervals being longer than five years is related to the tendency for births to be shifted to later than five years prior to the survey to avoid answering more questions (for example, see Pullum, 2006). With these longer, later birth intervals, estimates of secondary sterility may be inflated in the ZDHS datasets. However we see that estimates of sterility from the ZDHS datasets are well below those of the Gwembe Tonga (Figure 2.1).

There are some limitations to this measure. Some sexually inactive individuals may be included even when only including those who are married continuously. Excluding never-married and divorced individuals from the measure likely underestimates infertility; evidence suggests that subfecund women are more likely to be divorced than fecund women (Larsen, 1994). Contraception further complicates the measure as women who are practicing contraception could be counted as sterile despite being fecund. Larsen (1994) outlined contraceptive use conditions in which the subsequently infertile measure could be estimated with negligible

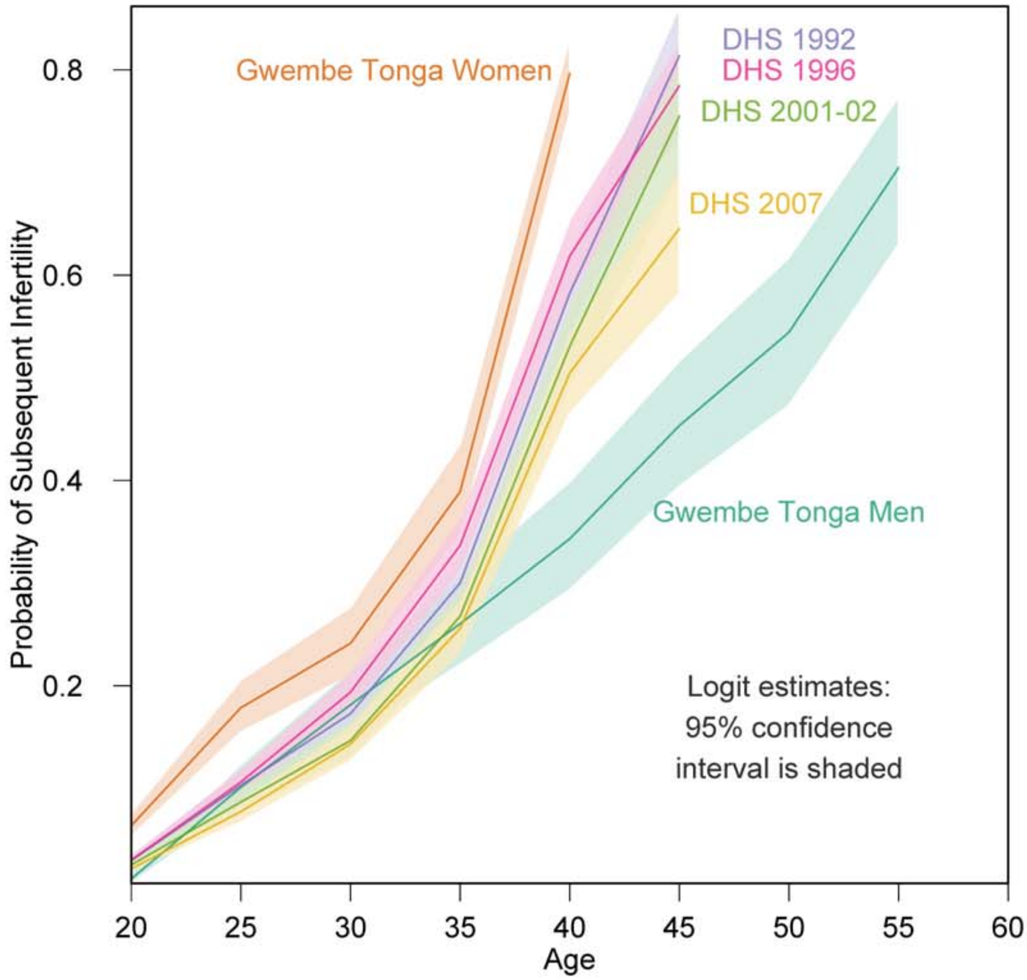

Figure 2.1: Predicted Probability of Being Subsequently Infertile

bias, but adequate detail about contraceptive use for determining whether these conditions are met is not available in the ZDHS (and often not available generally). In this analysis two ways of dealing with contraceptive use were used for the ZDHS data and are discussed briefly in the results.

This study uses discrete-time event history analysis (Allison, 1984). Logistic regression is used to estimate the hazard of being *subsequently infertile* by age and time. This approach incorporates covariates for age and time (calendar period). Sex and an interaction term between sex and age are included in the pooled Gwembe Tonga model to allow direct comparison of male and female sterility. A person-year file was created for the analysis. The time period (position on the calendar) corresponding to each person year was taken from the calendar date when the person-year started. All five-year age groups were included in all analyses, with the last age category for women being 40 or 45 years and older and mens age categories continuing to 55 years and older. Being sterile was measured with the *subsequently infertile* measure (Larsen and Menken, 1989, 1991). This indicator was defined for all observed person-years that were preceded by five consecutive years of being married. An individual was *subsequently infertile* in a given year if they were exposed to risk of pregnancy during the subsequent five years and did not have a live birth. Probabilities of being sterile were predicted for five-year age categories spanning reproductive ages. Gwembe Tonga men, Gwembe Tonga women, and each of the four ZDHS survey datasets were analyzed separately. Gwembe Tonga men and women were also analyzed in a pooled dataset to allow comparisons between male and female sterility. For the ZDHS models, including an indicator variable for Southern Province where the Gwembe Tonga live did not improve model fit and resulted in an odds ratio close to 1.0 whose 95% confidence interval included 1.0. Consequently we present ZDHS estimates for Zambia as a whole, rather than restricted to Southern Province. Results are presented for each of the seven models in Tables 2.3 and 2.5.

2.5 Results

The primary objective of this analysis is to produce estimates of sterility for men, something that is not generally done because birth history data for men are very uncommon. Male sterility by age is presented in Figure 2.1 along with estimates of female sterility from the

Gwembe Tonga and ZDHS datasets. These estimates are from the regressions in Tables 2.3 and 2.5 for each dataset and include 95% confidence intervals. The predicted probabilities can be interpreted as the proportion of the population experiencing sterility in an age group. Fewer men are experiencing sterility at any age than women. For example approximately 40% of Gwembe Tonga women are sterile by age 35, while sterility among Gwembe Tonga men does not reach that level until age 45. These age-specific differences between men and women are made explicit in Table 2.4, which provides the odds of being sterile for a woman compared to a man from the pooled model. While much higher at the youngest and oldest ages, in the middle of reproductive years, aged 30 to 34, women are only 1.5 times more likely to be sterile than men, indicating that their increased risk of sterility is felt most in their early and late reproductive years.

Tables 2.1 and 2.2 seek to illustrate the similarities and differences in marital and fertility behaviors across the data sets as well as provide the initial numbers of individuals from which the final set of observations was drawn. Ages at first marriage, ages at first birth, birth intervals, number of births and number of living children were similar for women in all datasets and similar for men in all datasets. For men and women, across all models, the odds of being sterile increased steadily with age, with near certainty of sterility at the oldest ages (which was an open interval and included all the oldest respondents under study); nearly 80% of Gwembe Tonga women and women in the earlier ZDHS data were sterile in the last age groups, whereas about 70% of men were sterile in their last age group, which was similar to women in the later ZDHS data (see Table 2.3 and Figure 2.1). This steady increase was true in the pooled model for men and women as well. From Figure 2.1 we can see the steady increase of the probability of being sterile with age is evident in all groups, but that the increase is much steeper for women than it is for men. Even though women in the later ZDHS surveys have probabilities of sterility at both young and old ages that are similar to Gwembe Tonga men, the slope of their increase in sterility with age is similar to that of the

Gwembe Tonga women and earlier ZDHS samples.

Contraceptive use among the Gwembe Tonga was negligible during the period under analysis (Sam Clark and Thayer Scudder, personal communication), so this was ignored in their estimates. Modern contraceptive use was increasing throughout Zambia in the period covered by the ZDHS surveys. For the four ZDHS datasets, the results shown in Table 2.5 consider all current users of contraception to be fertile. This represents a minimum level of sterility in the populations, as presumably a non-negligible proportion of contracepting women may be sterile but considered fecund. The models were also run (results shown here in Appendix A[2]) excluding all contraceptive users from the risk set entirely, which resulted in higher levels of sterility. In 1992 when only 16% of married women were using any method at the time of the survey, the estimated probability of sterility is similar for the two approaches, but by 2007 when 33% of married women were using contraception, the proportion of women who were sterile differed significantly between the two approaches, indicating a sizeable effect of contraceptive use on the measure (which was documented in Larsen (2000)). For comparison and discussion, only the estimates treating all contraceptive users as fertile are used, representing the minimum estimate of sterility.

Odds of sterility increased over time for all models (Tables 2.3 and 2.5.). This analysis is not intended to investigate the effect of time period on sterility because the relationship between time and sterility is complex and data on factors that may explain this relationship are not available. In this analysis time is included only to control for overall secular changes in the level of sterility.

2.6 Discussion

The Gwembe Tonga Research Project dataset provides a unique opportunity to estimate male sterility and compare the sterility of men and women. These findings demonstrate

[2]These results were not included in published paper.

that the prevalence of male sterility increases steadily with age, though not as sharply as for women. While sterility is less common among men generally, the difference is not constant over the life course. In fact, womens odds of being sterile are only moderately higher than mens in the middle of the reproductive years.

Larsen and Menkens *subsequently infertile* indicator was used to measure sterility. The reliability of paternity reporting is a potential limitation for any study of male sterility. In addition to the potential confusion of social and biological paternity, men may be unaware of children or choose to deny paternity. Data from both the Gwembe Tonga and ZDHS surveys indicate that most men reported at least one child. Data for the Gwembe Tonga were collected as part of annual censuses of the four villages; this limits recall bias that could undermine cross-sectional birth histories from men, especially in relation to births outside of stable, long-duration unions. The increasing prevalence of contraception in the more recent ZDHS survey data is another potential challenge for estimates of population sterility using this measure. Acknowledging this, we present results showing the lower bound of sterility. Obviously, high prevalence of female-controlled contraception would greatly complicate attempts to measure male sterility through birth histories, though for the period under study for the Gwembe Tonga, contraceptive use was negligible (Communication with the Gwembe Tonga Research Project). Sterility estimates for women in the ZDHS data were consistently lower than those for the Gwembe Tonga, this may be due in part to underestimation caused by including all contraceptive users in the risk set (assuming that they are all fertile when we know that a small fraction are not). The inclusion criteria used for the ZDHS samples was less strict with respect to marriage duration because data on union histories was less detailed. This may result in overestimation of female sterility because some of the women are not at risk of becoming pregnant. Additionally, substantially more women in the ZDHS samples reported last, closed birth intervals longer than five years than either Gwembe Tonga women or men. If ZDHS women do experience last birth intervals much longer than five years, the measure used here may overestimate sterility by classifying women as sterile after they have gone five years without a birth, even though they may go on to have additional births. However even with so many women in the ZDHS samples having last, closed birth intervals longer than five years, the mean length of the last birth interval was less than 3.5 years for all ZDHS samples, compared to 2.3 for Gwembe Tonga men and 2.7 for Gwembe Tonga women, and evidence suggests that about 10% of births may be inaccurately reported outside the five years prior to the interview to avoid additional questions in Demographic and Health Surveys (Pullum, 2006). Even with these two potential sources of upward bias in the estimates for the ZDHS samples, sterility estimates for the ZDHS women were lower than those for the Gwembe Tonga women.

This study shows that men's sterility increases with age similar to the age-related increase for women. However men's probability of sterility increases much more slowly than women's, which is expected due to men's longer reproductive period. In the final age group, men like women, reached very high probabilities of sterility.

Table 2.3: Odds ratios (with standard errors) for *subsequent infertility* obtained from logistic regression for Gwembe Tonga women, men and women and men pooled.

	Women	Men	Combined
Age Group			
20-24		Reference group	
25-29	3.5(0.3)*	10.7(2.4)*	10.7(2.4)*
30-34	5.5(0.6)*	22.8(5.4)*	22.6(5.4)*
35-39	12.3(1.4)*	40.8(10.0)*	40.1(9.8)*
40-44**	86.0(10.5)*	64.5(16.2)*	63.1(15.8)*
45-49***		106.4(27.2)*	154.3(38.9)*
50-54		158.4(42.8)*	
55+		338.5(96.7)*	
Time Period			
1950-1963		Reference group	
1964-1972	2.0(0.4)*	2.1(0.6)*	2.2(0.7)*
1973-1981	2.3(0.5)*	3.2(1.0)*	2.1(0.3)*
1982-1990	3.5(0.8)*	5.6(1.7)*	4.2(0.8)*
1991-1999	12.5(2.8)*	18.5(5.8)*	14.5(2.6)*
Sex			
Male			Reference group
Female			6.5(1.6)*
Sex and Age Interaction			
Female*25-29			0.3(0.1)*
Female*30-34			0.2(0.1)*
Female*35-39			0.3(0.1)*
Female*40-44			0.8(0.2)
Female*45+			2.3(0.7)*
Intercept	0.01(0.0)*	0.002(0.0)*	0.002(0.0)*
Pseudo R^2	0.32	0.29	0.31
Cases	1405	1021	2426
Observations	20069	16141	36210

*Significant at the p<0.01 level.

**For women only, the 40-44 age group includes all women age 40 and over.

***For the pooled model, the 45-49 age group includes all individuals age 45 and over.

Table 2.4: Odds of being *subsequently infertile* for women compared to men by age, computed from the logistic reaction with interaction terms for the pooled Gwembe Tonga men and women data.

Age	Odds
20-14	7.4
25-29	2.2
30-34	1.5
35-39	2.0
40-44	5.8
45+	15.6

Table 2.5: Odds rations (with standard errors) for *subsequent infertility* obtained through logistic regression for women from the 1992, 1996, 2001-02 and 2007 ZDHS, treating women using contraception as though they were fertile.

	1992	1996	2001-02	2007
Age Group				
20-24	Reference group			
25-29	3.5(0.3)*	3.5(0.2)*	3.5(0.3)*	3.8(0.3)*
30-34	5.7(0.5)*	6.5(0.5)*	5.8(0.5)*	7.3(0.7)*
35-39	10.4(1.1)*	12.3(1.1)*	11.0(1.2)*	14.3(1.6)*
40-44	31.0(3.8)*	33.2(3.7)*	31.2(3.9)*	37.9(5.2)*
45+	83.0(17.4)*	65.1(11.1)*	70.6(13.9)*	66.7(12.4)*
*Time Period***				
1964-1972	Reference group		No observations	
1973-1981	1.8(0.5)*	10.6(7.4)*	Reference group	
1982-1990	3.8(1.2)*	22.9(16.5)*	1.6(0.4)	Reference group
1991-1999	5.7(1.8)*	45.2(32.9)*	2.6(0.8)*	(1973-1999)
2000-2007	No observations		4.2(1.3)*	1.5(0.2)*
Intercept	0.01(0.0)*	0.001(0.0)*	0.01(0.0)*	0.02(0.0)*
Pseudo R^2	0.19	0.22	0.19	0.18
Cases	3399	3813	3744	3636
Observations	40233	45708	44099	43040

*Significant at the $p<0.01$ level.

**For the 2007 ZDHS most observations were in the latest time period and earlier time periods were combined to adjust for the relatively few observations.

Chapter 3

A PARSIMONIOUS CHARACTERIZATION OF CHANGE IN GLOBAL AGE-SPECIFIC AND TOTAL FERTILITY WITH A FOCUS ON SUB-SAHARAN AFRICA

3.1 Introduction

Fertility change remains an area of concern for demographers and policymakers in large part due to the continued rapid growth of the world population, set to reach 9.7 billion by 2050 with over 50% of growth occurring in sub-Saharan Africa (SSA) (United Nations, 2015b). Demographic transition theory posits that once begun fertility decline should be relatively steady and irreversible, and most demographers agree that fertility decline had begun virtually everywhere by the late 1980s (Bongaarts and Casterline, 2013) or the 1990s (Caldwell et al., 1992). Figure 1.1 shows trends in total fertility rates (TFR) for the world and world regions from 1950-55 until 2005-10, showing the decline across all regions, though with substantially different slopes. Analysis of the convergence of fertility has demonstrated that fertility levels around the globe are converging, which is suggested in Figure 1.1, though high fertility in SSA has been an outlier in global fertility convergence for decades (Dorius, 2008).

While most literature that seeks to characterize and understand fertility transition focuses on the TFR, a single number for a place and time, the TFR is built from age-specific fertility rates (ASFR). However, very different age patterns of fertility can produce the same TFRs, as can be seen in Figure 3.1, and the age pattern of fertility, and how it changes, is important for understanding fertility change in a population. In Figure 3.1 panel (a) six age-specific fertility curves corresponding to a TFR of 2.8 are shown. These curves are quite distinct from one another, with some curves, such as the Dominican Republic, Singapore and North Korea being very peaked, with fertility concentrated in a single age group, while others such as South Africa and Albania have highest fertility spanning at least age groups. In panel (b) curves corresponding to a TFR of 5.7 are shown, and these curves vary even more widely, with some starting with very high fertility at youngest ages and others having relatively high late fertility. Generally, fertility decline created through the control of fertility has been hypothesized to decline at older ages first, followed by a decline at the youngest ages. Knodel (1977) found evidence of this pattern in Europe and in most of Asia. Applying this pattern to Figure 3.1, one would theorize that South Africa 1965-70 and Indonesia 1955-60 have started decline and seen a drop in older age fertility, perhaps, while Libya and Tunisia still have high fertility at all ages. It would be difficult to assess Haiti's curve, which is relatively low at youngest ages but high at older ages. The decline in Latin America, generally, did not have a consistent pattern of changes in ASFRs, with countries falling broadly into three categories of ASFRs at the beginning of fertility decline, defined as early peak, late peak and dilated peak by Chackiel and Schokolnik (1996), with many countries maintaining the age structure they had at the beginning of decline. Other countries changed over time, transitioning from dilated to early peak, late to early peak, and others from a late to dilated peak (Chackiel and Schokolnik, 1996). Caldwell et al. (1992) argue that SSA decline will occur much differently from that seen in Asia and the West, due to different constraints on premarital and extramarital sexuality, differences in marital stability, and different emphases on the need and reasons for birth spacing; and they hypothesize that in SSA the fertility decline will occur at all ages. Applying the characteristics of Western and Asian fertility decline, including marked decline at oldest ages and/or highest parities, to SSA, van de Walle and Foster (1990) found "considerable uncertainty about the causes and permanence of these trends", indicating, at least in part, that SSA was not exhibiting the patterns associated with early decline seen by Knodel (1977) or others. More recent work by

Moultrie et al. (2012) has found widening birth intervals at all ages and parities associated with fertility decline in SSA, supporting Caldwell et al. (1992)'s claims of differences in the SSA decline at least in part. However, questions remain about how SSA age-specific fertility curves fit into a global context. Furthermore, how do patterns identified and established for the West and East Asia compare to the patterns that have been witnessed in the ongoing fertility declines in Latin America and the Caribbean and in the rest of Asia? How do the fertility profiles of North Africa and the Middle East fit into a global discussion of age-specific fertility trends?

The question this approach is seeking to address is, can commonalities be found in *how* age-specific fertility changes across world regions and across time, and do these patterns provide insight into the future of fertility in areas with persistent high fertility? This paper seeks to address primarily the first portion of this question by applying a novel approach to investigating age-specific fertility over time and across countries and searching for patterns that can be associated with fertility decline.

This paper aims to present an analytical approach to understanding global fertility trends from 1950-2010 utilizing age-specific fertility rates, from the UN World Population Prospects. To create a quantitative characterization of fertility schedules for comparison through time and across countries, ASFRs are considered rather than the TFR. This approach acknowledges the different ASFRs that may aggregate to similar TFRs but mean something different about fertility transition or decline. This approach is similar to methods used previously (e.g. INDEPTH Network, 2002; Clark et al., 2009; Clark, 2014; Sharrow et al., 2014) and makes use of singular value decomposition (SVD) to decompose age-specific fertility curves and reduce the number of parameters needed to describe them.

Other methods have been used to investigate age patterns of fertility. The Coale and Trussell (1974) model of age-specific fertility rates based on first marriage patterns and martial age-specific fertility and estimates of m has been used to determine the level of

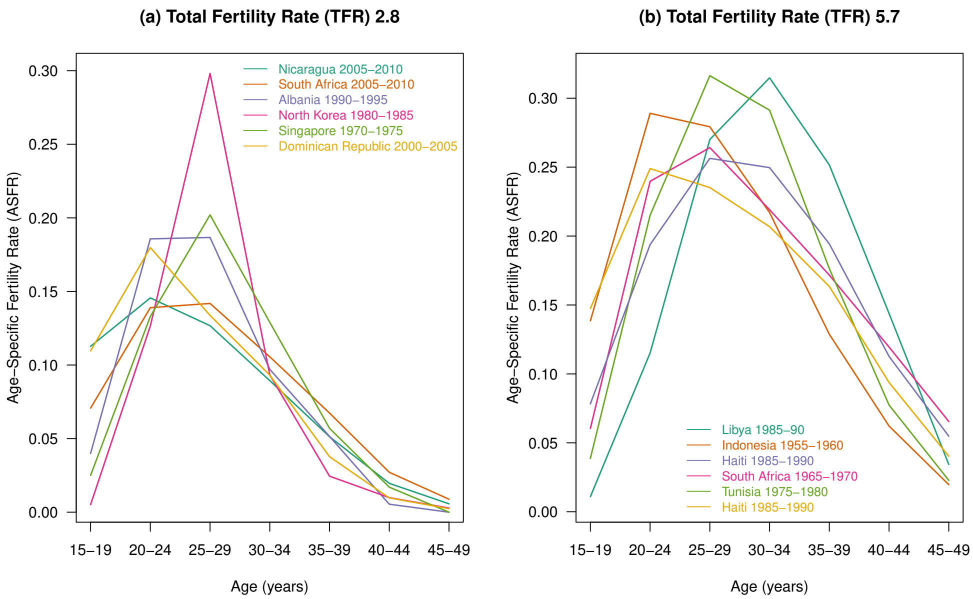

Figure 3.1: Example Age-Specific Fertility Curves Producing the Same Total Fertility Rate: (a) shows a selection of age-specific fertility curves that create a total fertility rate of 2.8; and (b) shows different curves that sum to a total fertility rate of 5.7. Data from United Nations (2013).

fertility control in a population. However, this approach is focused on marital fertility, which, given the data available and importance of non-marital fertility in the most recent decades, is of limited interest in understanding recent fertility trends or for making fertility projections. The Lee-Carter method for fertility projection, based on their mortality projection method, applies SVD to the age-specific residual remaining after subtracting mean age-specific fertility (Lee, 1993). The approach used in this paper is similar but importantly different from theirs. In this approach, the age-specific fertility rates are not mean-subtracted; SVD of the age-specific data is computed directly; and more than the first component is used because of the interest in better understanding the changes in age-specific fertility over time, rather than building a projection model for the TFR, as was the aim of Lee's fertility models.

Hyndman and Ullah (2007) build on the Lee-Carter method, extending it to functional data by conducting a functional PCA on smoothed data and using ARIMA models for the forecasting. A major difference in this approach is that fertility regimes from multiple countries over time are included, instead of looking at just one country's regimes over time. Data are not smoothed in any fashion, though the data are already smoothed, somewhat, as these fertility data undergo some manipulation before publication by the UN.

3.2 Data

Data used for this analysis come from the UN's World Population Prospects (WPP) 2012 Revision (United Nations, 2015b). ASFRs are provided for all countries in five year intervals from 1950-55 to 2005-10 for five year age groups (ages 15-19 to ages 45-49). Countries with a population of at least one million were included in the analysis; 154 countries met this criteria. Three countries, Yemen, Gabon and Timor-Leste, had outlier TFR trajectories that suggested problems with their data or extremely exceptional fertility trends, so they too were excluded. Six age-specific fertility rates are used (age 15-19 years, 20-24 years, 25-29 years, 30-34 years, 35-39 years, and 40-44 years) for the 12 time periods. The last age group, ages 45-49, was omitted from this analysis because the fertility rates for that age group were so close to zero, or were zero, and inclusion greatly influenced the results of the analysis at the expense of details related to fertility at earlier and higher fertility ages. Logged ASFRs are used for the analysis. All visualizations show exponentiated results so that curves are analogous to fertility rate curves.

Data from the UN WPP are the most complete data available for global fertility and provide data for 50 years for all countries in the world, though these data are already processed, and to an extent, smoothed by the UN. No other data cover as much time for the globe. Additionally these are the same fertility data used by the UN Population Division to inform their global estimates and population projections, and thus finding patterns and understanding the trends in these data will be useful for informing predictions of fertility. These same data have been used in comparative analyses of fertility trends elsewhere as well (e.g. Dorius, 2008; Bryant, 2007; Wilson, 2001; Casterline, 2001).

An illustrative example is presented below using data from the Human Fertility Collection (Human Fertility Collection, 2015). Swedish data provide annual age-specific fertility from 1891-2011 for each age 15-50 years. These data were chosen for illustrative purposes because of their high quality over a duration that covers high fertility through decline to replacement and the period of below-replacement fluctuations, thus allowing a full view of fertility change by year.

3.3 Methods

This section summarizes the material in Clark (2014) which presents this method and its application in full detail.

The singular value decomposition (SVD) (e.g. Strang, 2009) factorizes a matrix $\mathbf{X}$ such that

$$\mathbf{X} = \mathbf{U}\mathbf{S}\mathbf{V}^{\mathrm{T}} , \tag{3.1}$$

where $\mathbf{U}$ contains the orthonormal (independent, unit length) 'left singular vectors' $\mathbf{u}_i$ (columns of $\mathbf{U}$), $\mathbf{V}$ contains the orthonormal (independent, unit length) 'right singular vectors' $\mathbf{v}_i$ (columns of $\mathbf{V}$), and $\mathbf{S}$ is a diagonal matrix containing the 'singular values'.

The right singular vectors are a new set of orthonormal dimensions for the points defined by the rows of $\mathbf{X}$. The product of the left singular vectors and their corresponding singular values are the projections of the points defined by the rows of $\mathbf{X}$ along the new dimensions defined by the right singular vectors.

The SVD is estimated by minimizing the distance between the actual points (rows of $\mathbf{X}$) and the best approximations of those points using successively more of the new dimensions defined by $\mathbf{V}$. The singular values correspond to the fraction of the overall squared distance from the origin to the points along the new dimensions $\mathbf{V}$ that is captured by each individual new dimension $\mathbf{v}_i$. The first new dimension is oriented to capture as much of this squared distance as possible, and each successive new dimension captures the most possible of what remains.

The product of the SVD factors can be algebraically rearranged to yield another equivalent expression called the *Eckart-Young-Mirsky formula* (Golub et al., 1987)

$$\mathbf{X} = \sum_{i=1}^{\rho} s_i \mathbf{u}_i \mathbf{v}_i^{\mathrm{T}} \ . \tag{3.2}$$

Equation (3.2) expresses $\mathbf{X}$ as a sum of rank-1 matrices, where ρ is the rank of $\mathbf{X}$. By construction (above) the first term in this sum captures or explains the bulk of the variation in the original data (rows of $\mathbf{X}$), and each subsequent term explains less and less. The expression for $\mathbf{X}$ in Equation (3.2) can be further rearranged to express each column vector $\mathbf{x}_\ell$ in $\mathbf{X}$ as

$$\mathbf{x}_\ell = \sum_{i=1}^{\rho} s_i v_{\ell,i} \mathbf{u}_i \ . \tag{3.3}$$

Equation (3.4) says that we can write all the columns in $\mathbf{X}$ as weighted sums of the left singular vectors scaled by their corresponding singular values. The weights are the ℓ^{th} elements of each corresponding right singular vector. Moreover, the Eckart-Young-Mirsky matrix approximation theorem (Golub et al., 1987) reveals that these sums have the property of concentrating most of the variation in the first few terms, and consequently we only need the first few terms to produce approximate values for $\mathbf{x}_\ell$ that are very close to the actual values. This allows one to closely approximate the columns of $\mathbf{X}$ with (potentially very) few effective parameters – just the first few weights.

Using the SVD, the $6 \times 1,848$ (age $\times$ country, time) matrix of ASFRs from the UN WPP data is factored into $i \in \{1, \ldots, 6\}$ orthogonal age-varying components $s_i \cdot \mathbf{u}_i$ (the left singular vectors scaled by their corresponding singular values, six elements each, one for each age group) and country-time-varying weights associated with those components, the 1,848 elements of each $\mathbf{v}_i$.

Following Clark (2014), the first component $s_1 \cdot \mathbf{u}_1$ is the underlying 'shape' of the age-specific fertility schedules ($s_1\mathbf{u_1}$ in Figure 3.2), and the remaining components define increasingly subtle refinements to that underlying shape. As the Eckart-Young-Mirsky matrix approximation theorem suggests, adding additional components, or terms to the sum in Equation (3.4), adds increasingly more refined but less consequential nuances to the reconstructed fertility schedule, until when all components are included, the reconstruction is equal to the original. In this application the first three components, $s_1\mathbf{u_1}$, $s_2\mathbf{u_2}$ and $s_3\mathbf{u_3}$, are retained and shown in Figure 3.2. $s_1\mathbf{u_1}$ can be seen to have the general shape of an age-specific fertility curve, while $s_2\mathbf{u_2}$ decreases (or increases) early or late fertility and $s_3\mathbf{u_3}$ accentuates how peaked or flat the curve is. The adjustments made by the second and third components are relatively subtle refinements (dependent on the magnitude of their $\mathbf{v_i}$ values) but provide important differentiation between age-specific fertility curves over time and across countries.

Focusing on the first three components in the Eckart-Young-Mirsky approximation of the fertility schedules, we use the first three left and right singular vectors and singular values are used and closely approximate the majority of the 1,848 empirical fertility schedules included in the matrix originally factored using the SVD. Consequently, the model of age-specific fertility used is

$$\mathbf{f}_{c,t} = \sum_{i=1}^{3} v_{i,c,t} \cdot s_i \mathbf{u}_i \ , \tag{3.4}$$

where $\mathbf{f}_{c,t}$ is the age-specific fertility schedule for country c in time period t, and i indexes the three SVD-derived age-specific components that we retain. The columns of the original data matrix $\mathbf{X}$ are country and time-specific; hence each column is identified by a unique combination of c and t.

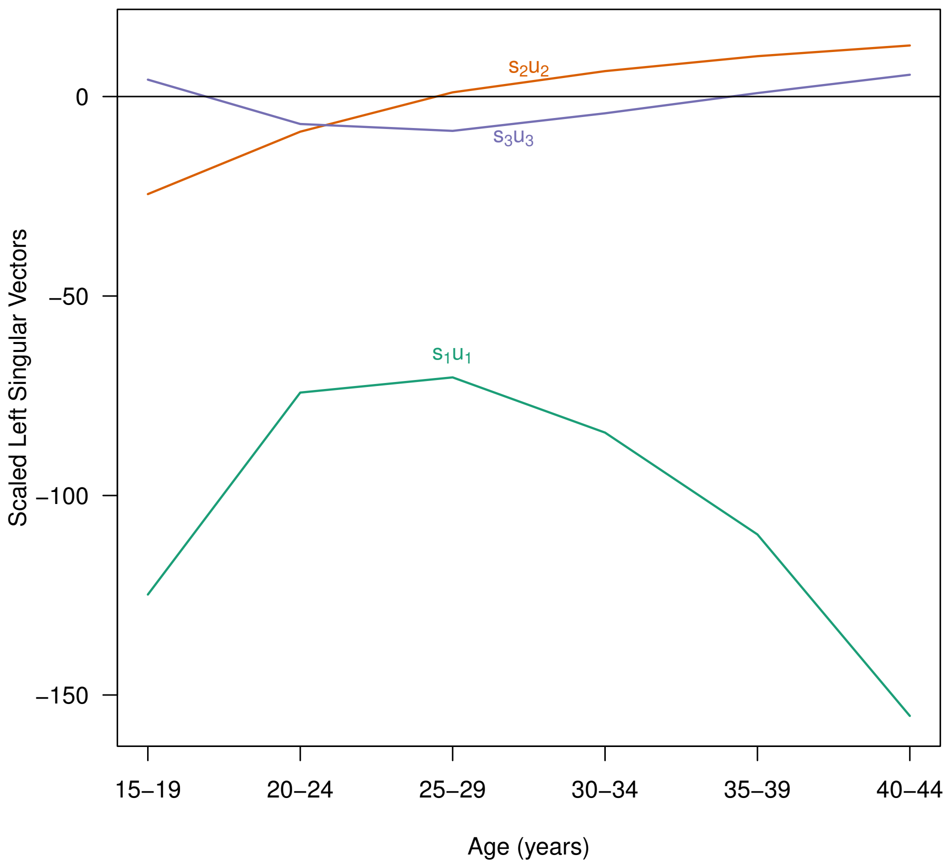

Figure 3.2: First Three Components (scaled left singular vectors) from Singular Value Decomposition Factorization of Age-Specific Fertility Schedules.

The SVD factorization allows one to work with a high quality, three-parameter approximation of the full age-specific fertility schedules. Beyond having fewer dimensions, the SVD factorization produces effective parameters, the v weights, that are independent and interpretable because they are associated with fixed age-specific components whose age profiles are meaningful.

We describe how the weights (elements of the right singular vectors) change through time by country and region, and using the `mclust`[1] model-based clustering method, we group the two-element 'weight vectors' associated with each age-specific fertility schedule into clusters of similar weight vectors, and hence similar fertility schedules. Each resulting cluster has its own characteristic age pattern of fertility.

3.4 Illustrative Example with Data from Sweden

Data for Sweden available from the Human Fertility Collection (Human Fertility Collection, 2015) cover high fertility in the 1890s through Sweden's initial fertility decline, baby boom and post-transition, low fertility years, hence providing a time series that covers nearly all of Sweden's fertility decline (data are not available for highest levels of fertility and so there is no data included for fertility levels near pre-transition levels seen in non-Western regions). Figure 3.3 shows Sweden's TFR over time for the data used.

Using the Swedish data, similar components are obtained from the SVD (see Figure 3.4 (a)) as we see in Figure 3.2 for the UN WPP data. The main difference is that the curves are much smoother because age is in single years. Additionally, we see even more nuance in the second and third components. For the UN WPP data, we retain three out of six total components, however for Sweden we achieve a similar level of detail retaining *three out of 35 components* (more total components are obtained for Sweden because the initial matrix is 121 years by 35 ages). Component two is primarily functioning to accommodate lower early fertility and higher later fertility (or the opposite for weights of opposite sign) though there is some nuance in how this is affecting the oldest age groups because the oldest age group's fertility is not changing. The third component has a similar structure here as for the UN WPP data, though more nuance through the 20s and 30s, the ages of highest fertility across

[1]Model-based clustering is conducted using the `mclust` package in R (Fraley et al., 2012) on the second and third weights selected from the SVD results. Bayesian Information Criteria (BIC) is used to select the optimal number of clusters

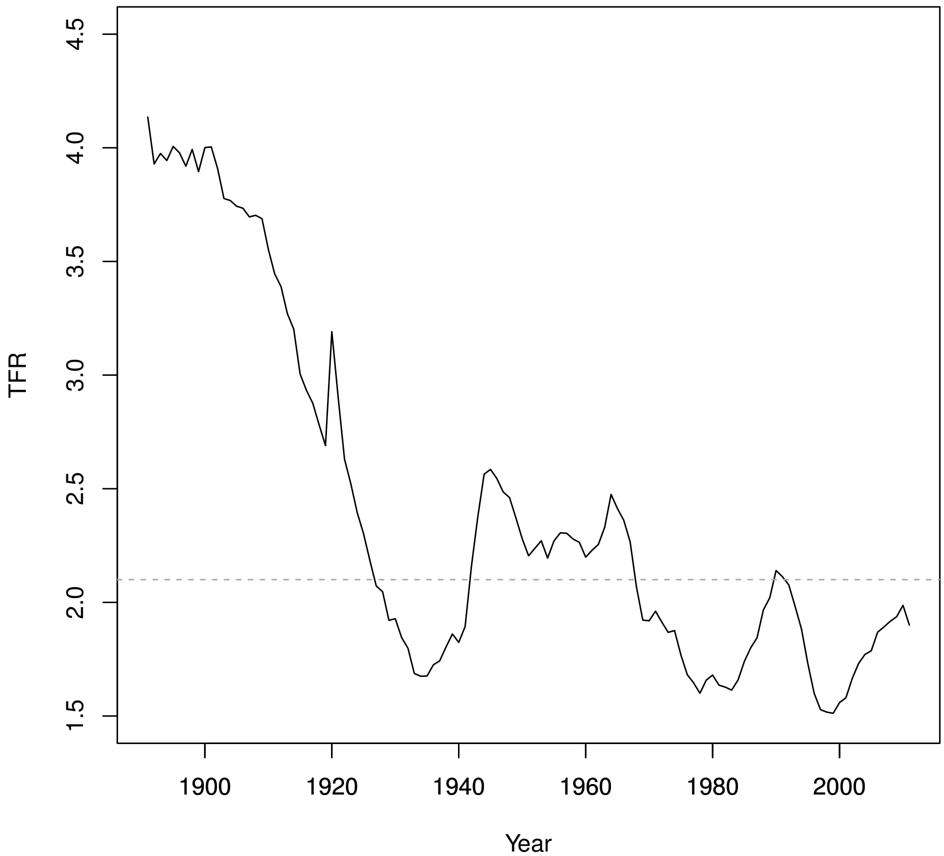

Figure 3.3: Total Fertility Rate for Sweden from 1891 to 2011

this data.

Panel (b) in Figure 3.4 shows how the weights on the first component change with time. Generally this weight is increasing, which corresponds to a decline in overall fertility levels, and peaks in the 80s and 90s before declining in the most recent years, which is consistent with the TFR over these years. Additionally there are breaks in the pattern of declining fertility corresponding to World War II and the baby boom, and to a lesser extent World

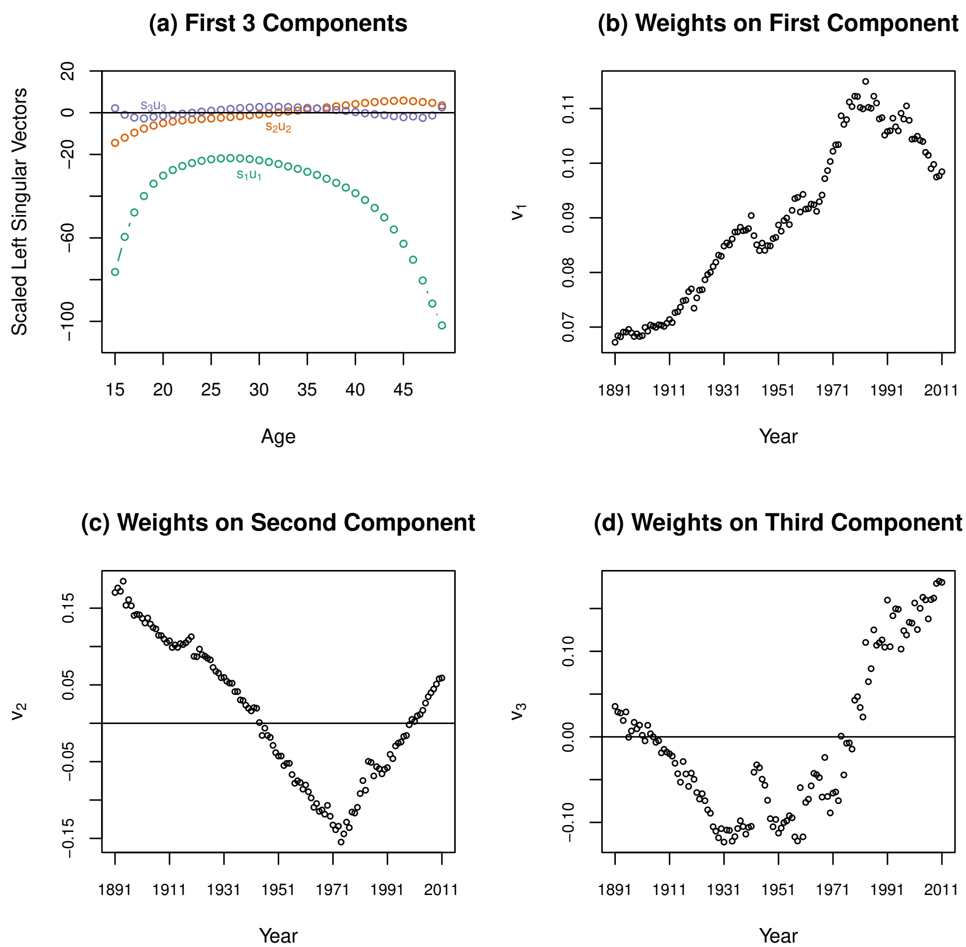

Figure 3.4: Singular Value Decomposition Results for Swedish ASFR 1891-2011. (a) Scaled left singular vectors, showing the first 3 of 35 components from the SVD; (b) Weights (v_1) associated with the first component ($s_1\mathbf{u_1}$); (c)Weights (v_2) associated with the second component ($s_2\mathbf{u_2}$); (d) Weights (v_3) associated with the third component ($s_3\mathbf{u_3}$)

War I and the global flu pandemic of 1918.

Panels (c) and (d) in Figure 3.4 show the weights for the second and third components over time. Of note is that even for these more nuanced components we can see visible impacts of historical events. The weights on the second component have a noticeable increase around the end of World War I and the 1918 flu, with a less distinct one occurring around the end of World War II, indicating a relative increase fertility at later ages (or a shift in the peak fertility ages to slightly older ages). Otherwise the weights are declining regularly from the beginning of the data through the early 1970s passing through zero, which indicates shifts to lower fertility at older ages and a shift of peak fertility to younger ages. From the 1970s, the trend reverses completely, with a steady increase in the values of the weights, even passing into positive values again, though there is a notable blip around the late 1980s, associated with a shift towards higher fertility in later years. The third component similarly starts declining from the beginning of time under study, which corresponds to a flattening of the age-specific fertility curve. However, third component weights are quite volatile from the late 1930s through the 1960s, taking on a strange shape. Following 1960, these weights incline steadily, corresponding to fertility being concentrated in fewer ages, or a more pronounced peak in the curve. Likely, the trends seen starting in the late 60s for these weights are associated with the availability of modern contraception profoundly shaping fertility behaviors.

3.5 Results for Global Fertility Trends from 1950-55 through 2005-10

3.5.1 Results from SVD

Figure 3.2 plots the shapes of the age-specific curves of the first three components, denoted as $s_i\mathbf{u_i}$. The first component captures the overall shape of the curve of fertility with age, rising steeply from the first age to a peak in the second through fourth age groups, and steadily declining again. The weights on $s_1\mathbf{u_1}$ are all positive. Larger weights on $s_1\mathbf{u_1}$ result in lower fertility, pulling the curve down, and smaller weights result in higher fertility, pushing the curve up.

The second component adjusts the earliest and oldest age groups, to accommodate higher or lower early or late fertility, while the third component adjusts the peak fertility age, in the 20s and early 30s, either flattening the curve or intensifying the peak. Positive weights for the $s_2\mathbf{u_2}$ curve bring fertility down in the earliest age groups while simultaneously pulling up fertility at later ages, leaving fertility levels at the second age group unchanged (the opposite would occur with a negative weight on $s_2\mathbf{u_2}$, pulling up earliest fertility while suppressing later fertility). Similarly, depending on the sign of the weight on $s_3\mathbf{u_3}$, combining this curve with $s_1\mathbf{u_1}$ accentuates/de-accentuates the peak seen at ages 25-29, pushing up the fertility at these ages while suppressing fertility at the extreme ages. Subsequent components made further, more complex and more subtle adjustments to the basic curve given by $s_1\mathbf{u_1}$.

SVD Weights over Time

The country-time specific SVD-derived weights, $v_{i,c,t}$ are a parsimonious description of country-specific changes in age-specific fertility rates. Panel (a) in Figure 3.5 shows the weights for the first component for each country over time, with the color indicating the world region (See Appendix B for countries in each world region). Higher values of $v_{1,c,t}$ are associated with lower overall fertility and the median curve shown in black shows that values of $v_{1,c,t}$ have been steadily increasing globally since the 1960s. Though world regions do overlap, SSA countries are predominantly at the bottom of the graph, with the lowest values of $v_{1,c,t}$ through time and with the smallest increase over time. The West, comprised of the US, Canada, Australia, New Zealand and Europe, had some of the highest values for this weight in the earliest years and have maintained, after a rise in the 1960s and 1970s, high values for this weight. For East Asia we can see a dramatic increase from low levels to the highest values of $v_{1,c,t}$.

Weights on the second component are largely centered around zero and the variance is much smaller than seen for $v_{1,c,t}$ in Panel (b) of Figure 3.5. Looking at the way $v_{2,c,t}$ changes over time for each country, colored by world region, there are no clear regional patterns such as are present in the relationship between $v_{1,c,t}$ and time. However, SSA countries seem highly concentrated near zero, in contrast to other regions that experience more variation

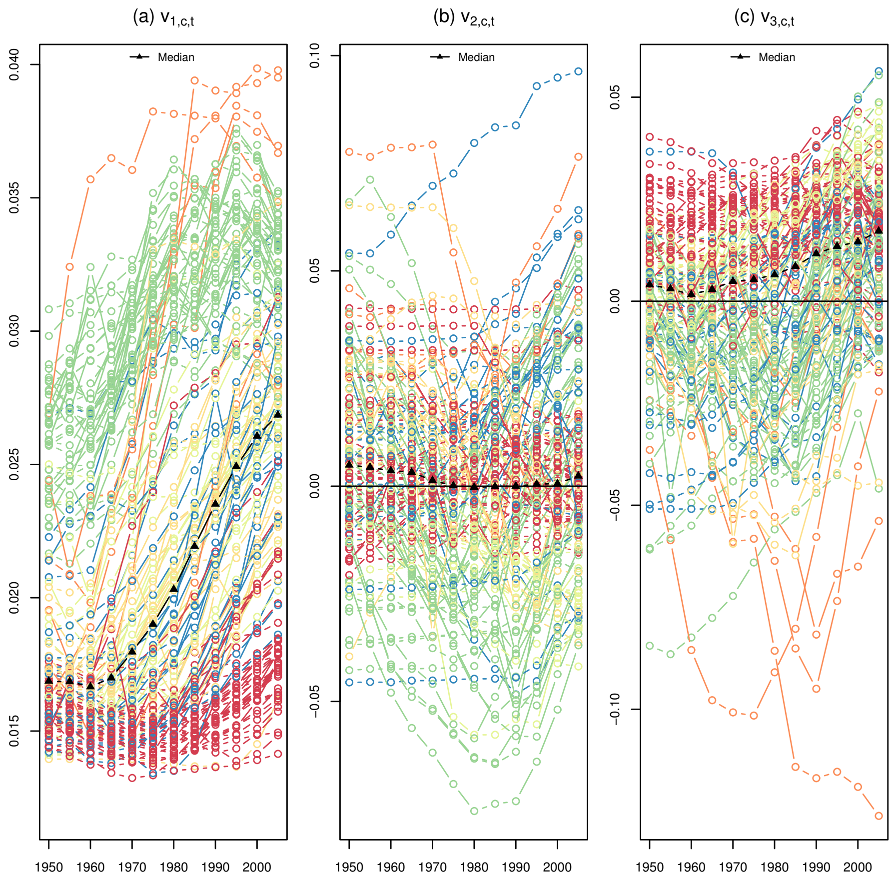

Figure 3.5: Weights on Each Component by Country from 1950-55 through 2005-2010: (a) shows the first component weights, $v_{1,c,t}$; (b) shows the second component weights, $v_{2,c,t}$; and (c) shows the third component weights, $v_{3,c,t}$. Colors indicate world region: red for sub-Saharan Africa, orange for East Asia, yellow for South Asia, light green for Latin America and the Caribbean, green for the West, and blue for the Middle East and North Africa.

in values of $v_{2,c,t}$ over time. *This clearly reveals the lack of age-specific fertility change in SSA compared to other world regions.* Tracking individual country lines through time, there appear to be substantial changes in values of $v_{2,c,t}$ period to period as well as a wide variety of patterns for overall time trends. Some patterned behavior can be seen for both East Asia and the West, while most other world regions exhibit far less variability and less dramatic change over time.

Weights on the third component, $v_{3,c,t}$, over time for each country are shown in Figure 3.5 Panel (c). Like the second component, these weights are largely concentrated around zero and regional patterns for changes in $v_{3,c,t}$ over time do not seem particularly pronounced, though SSA countries seem concentrated just to the positive side of zero, while East Asia and the West seem to have much higher volatility in values and predominantly negative values for $v_{3,c,t}$. As the third component is responsible for how peaked the fertility curves are, we see that SSA values are associated with flatter curves, or curves with peaks that span over more age groups, while the West and especially East Asia have curves that are quite peaked with highest fertility occurring in only one age group. This corresponds to general patterns of low overall fertility in these areas, one to two births, often relatively close together while in SSA the highest fertility years span more ages as women tend to have more than two children with substantial spacing in some instances (Bongaarts and Casterline, 2013).

3.5.2 Clustering Results

The first component provides overall level for a standard age-specific fertility curve. The exponentiated $v_{1,c,t} \cdot s_1\mathbf{u}_1$ curves for the 1848 country-periods included in the data is shown in Figure 3.6. This curve shows the age-specific fertility curve reconstructed from only the first component and the curve created using the median values for $v_{1,c,t}$ is shown in black. As seen above, this component functions much like TFR, capturing fertility levels. To explore how, independent of fertility level, age patterns of fertility may be similar or different across time and place, we have clustered the weights for the second and third components, which capture differences in young and old fertility and how peaked the fertility curve is. Four clusters of similar age-specific fertility curves were obtained from clustering vectors of the second and third weights. The reconstructed, exponentiated curves obtained are shown in

Figure 3.7, which shows the median curves created by looking at the weighted second and third components for each cluster, with the interquartile range shaded and extrema values shown as dotted lines. Effectively, these curves show the variation seen in that cluster net of the basic age-specific fertility curve provided by the first component.

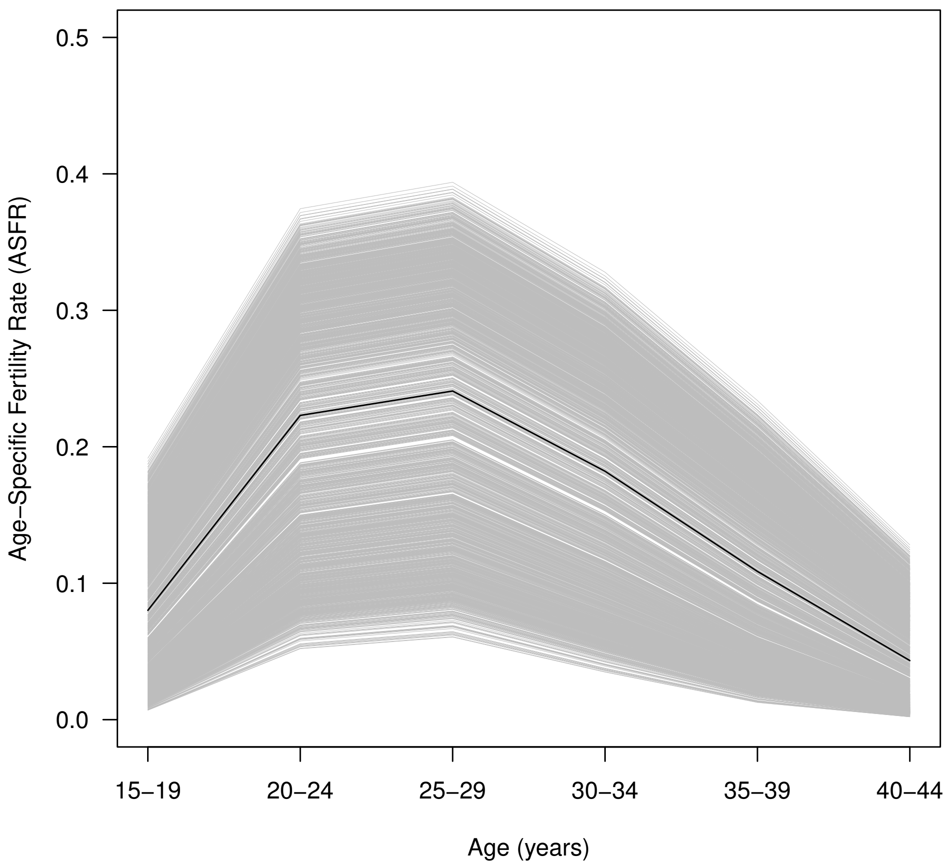

Figure 3.6: Age-Specific Fertility Curve Reconstructed from First Component Only. Median age-specific fertility curve constructed from the first SVD component only shown in black. All curves constructed for each county and time period shown in gray.

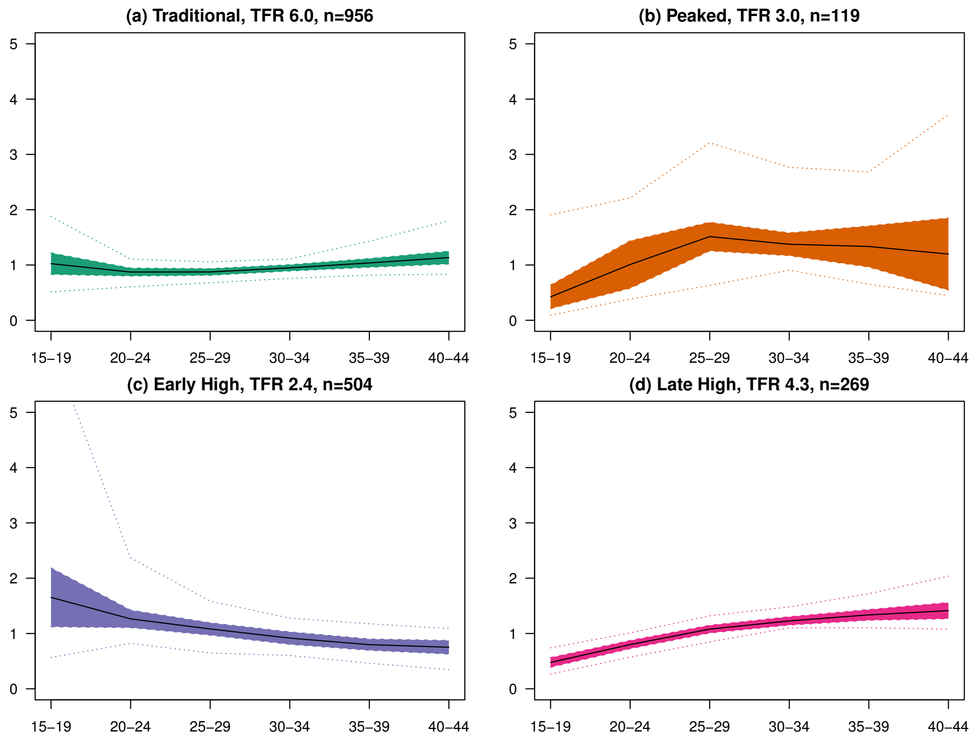

Figure 3.7: Changes to General Age-Specific Fertility Curve by Cluster. Median curve is shown with interquartile range shaded and dotted lines showing extreme values for combined changes to the base age-specific fertility curve by including weighted components 2 and 3 for each of the 4 clusters: (a) the Traditional Curve cluster; (b) Peaked cluster; (c) Early High cluster; and (d) Late High cluster. Values of 1 represent no change to the base curve.

The Traditional cluster has the most classic curve, with minimal variation from the curve created by the first component. This cluster has the highest median fertility, with a TFR of 6, but has curves with a wide range of TFRs, from 0.9 to 8.3. In this cluster, peak fertility occurs at ages 25-29 years, and highest fertility spans ages 20 through 34 years. Fertility is relatively low in the youngest ages and declines steadily and gradually through the 30s and 40s, with fertility at the oldest age group lower than that of the youngest age group. Most SSA curves are in this cluster, and all world regions have curves in this cluster. The Traditional cluster was the largest cluster with 956 age-specific fertility regimes.

The Peaked cluster diverges from the basic curve obtained by the first component with a distinctive peak in the middle reproductive years after a rather sharp increase from low early fertility and a relatively sharp decline afterwards. The median curve places this distinct peak at ages 25-29, though curves in this cluster may have earlier peaks, later peaks or peaks that span more than one age group. This cluster had the fewest members, 119 curves, though there is substantial variation in the shape of these curves apart from the unifying peak. The median TFR for these curves is 3.0 but TFRs ranged from 8.0 to 1.0 in this cluster. This cluster contains no curves from Latin America and the Caribbean or from SSA.

The Early High cluster is named for its higher fertility at early ages. The median TFR for its 504 member curves was 2.4, over a range of 7.6 to 1.2. The median curve for this cluster peaks at ages 20-24 and then declines steadily. Generally, these curves have a slight decrease or even an increase in fertility from ages 20-24 to ages 25-29 followed by a gradual decline to the oldest ages (some with very slow decline). Curves from all regions except East Asia are represented in this cluster.

The Late High cluster is named for its higher fertility at older ages. These curves are similar to those in the Traditional cluster, but while the curves in the Traditional cluster have fertility concentrated at and before ages 25-29 years, in this cluster's curves fertility is concentrated in ages 25-29 and 30-34 years. Also, fertility at the youngest ages is lower in this cluster than in the Traditional cluster. TFRs for these curves range from 8.4 to 1.2 for the 269 member curves, and median TFR is 4.3. No curves from Latin America and the Caribbean are included in this cluster.

Figure 3.8 shows the TFR trends for selected countries from 1950-55 through 2005-10 with the associated cluster membership shown for each period. Three countries from SSA are shown here, Kenya, Togo and South Africa, chosen because of their evident fertility decline in the past few decades. Kenya and Togo are in the Traditional cluster for all the periods shown here, indicating they kept a relatively stable age-specific fertility regime through their fertility declines. South Africa started in the Late High cluster in the initial periods covered but has been categorized as Traditional since 1965-70 and throughout its decline to near replacement fertility. This pattern is consistent with that seen for Iran, also shown, which had a precipitous decline without changing from its categorization in the Traditional cluster, indicating minimal changes to its age-specific fertility curve. Sri Lanka, as well, was categorized in the Traditional cluster throughout its fertility decline, except for one period (1975-80) that was categorized as Late High. Argentina's fertility was largely stalled throughout the period under study with some decline to replacement levels seen towards the end of the study period; Argentina's fertility curves were categorized as Traditional for all periods under study. South Korea and Sweden are included for comparison. South Korea is an example of a country with many Peaked fertility curves. Early South Korean curves were categorized as Late High and then during the decline changed to Peaked. Curves were categorized as Peaked through the decline to below replacement levels. Meanwhile curves from Sweden were included in all clusters. Curves from the first two periods were Traditional. Afterwards Swedish fertility saw a decline to below replacement levels during which the curves were categorized as Early High. One period was categorized as Peaked, followed by two periods categorized as Late High, and finally the curve for the last period was categorized as Traditional. These last fluctuations from cluster to cluster correspond to a period of volatile TFR as Sweden's fertility rose above and then dropped below replacement levels.

Clearly, patterns of decline in SSA's more advanced fertility declines show similarities to patterns seen in other regions, suggesting the fertility behaviors outlined in Caldwell's African Exceptionalism will not necessarily keep SSA countries from seeing fertility decline similar to patterns seen in other countries, if not comparatively delayed. Instead, these similar patterns in the more advanced declines of SSA point to interpretations of Bongaarts and Casterline (2013) that SSA fertility decline remains early and suggesting that changes in fertility regimes will accompany decline in recognizable patterns.

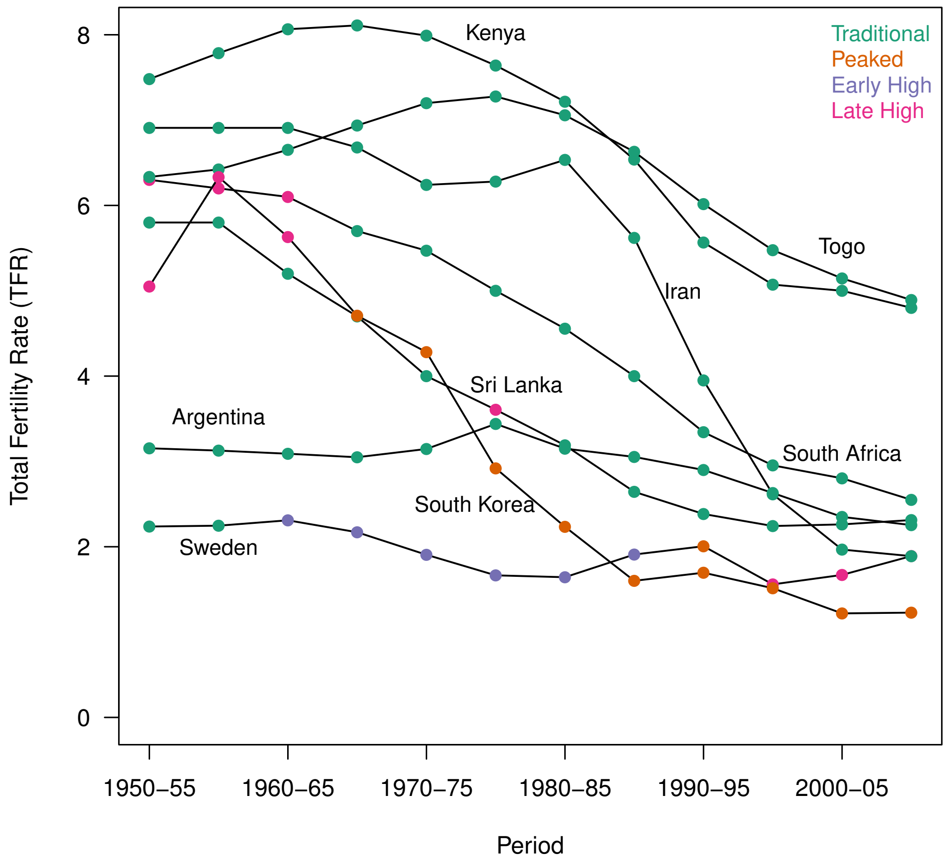

Figure 3.8: Trends in Total Fertility Rates with Cluster Assignments for Select Countries

3.6 Conclusion

Incorporating age patterns of fertility directly in modeling provides more depth to the analysis of global fertility trends by making explicit how changes in fertility may occur within stable age patterns of fertility and also how changing age patterns of fertility may result in only small TFR changes in the short-term. This analysis makes explicit the idea that many different patterns of fertility can result in similar levels of fertility, or that different levels of fertility can have very similar age patterns. Seeing that no particular age pattern structure was associated with particular fertility levels support Hirschman (1994)'s observation that a high fertility regime may take many different pathways to arrive at lower fertility (Hirschman, 1994). By reducing the fertility curves using the SVD, we are able to look at these patterns with few parameters without losing detail, which simplifies analysis. This simplification suggests immediate next steps, specifically utilizing these outputs to test directly how factors hypothesized to contribute to fertility decline are affecting both fertility level (the first component) and the age structure of fertility (the second and third component).

These results support the primacy of the overall level; the explanatory strength of first SVD component and the large membership of the Traditional cluster suggest that the general fertility curve is the most prevalent. However, from the clustering results a distinctive patterning of differences in age-specific fertility curves not associated with fertility level are evident. Categorizing the fertility regimes into clusters visualizes how changes in the age structure of fertility are occurring differently across fertility declines. There is some regional patterning in how age-specific fertility is changing during fertility decline, which is further supported by looking at the SVD weights directly. Looking at the weights on the SVD components and looking at the clustering results, there is very little change in age-specific fertility patterns in SSA. However, also there is virtually no change in these patterns in Latin America and the Caribbean, and for some Asian countries. Casterline and Odden (2016) also find similarities in birth intervals between SSA countries, Latin America and the Caribbean countries and some Asian countries. Among these countries there are examples where countries have maintained a traditional age-specific fertility curve throughout fertility decline to replacement fertility levels, effectively experiencing decline at all ages more or less simultaneously. In addition, some Western countries are returning to this standard age-specific fertility curve with post-replacement stabilization. Considering SSA fertility trends in their global context this way, the relative stability in age patterns of fertility does not indicate that substantial fertility decline will not occur and, in fact, as seen in some countries in Latin America and the Caribbean, decline could be relatively sudden even without a change in age patterns of fertility. For example, South Africa and Kenya (Figure 3.8) are following trajectories of both fertility decline and cluster membership (indicating age-specific fertility behaviors) similar to those seen in countries like Iran and Sri Lanka, which have reached replacement or near replacement fertility levels in recent decades.

This analysis demonstrated that dimension reduction of age-specific fertility curves is possible and that with reduced dimensions a coherent story of historical trends can be visualized and analyzed. The Swedish example, with the high quality, annual data spanning over a century illustrates the level of detail in age-specific fertility schedules that can be retained in a fraction of the dimensions. In the global analysis, investigating the patterns of fertility decline and age-specific fertility concurrently make possible comparisons of patterns of age-specific fertility curves over time across countries; this comparison provides a global context for fertility behaviors seen in individual countries or regions. Specifically, investigating how SSA age-specific fertility patterns fit into global patterns, it becomes evident that SSA countries with more advanced fertility declines, their patterns of age-specific fertility are similar to patterns found in other regions.

Chapter 4

AGE-SPECIFIC FERTILITY AND FERTILITY CHANGE: THE ASSOCIATION BETWEEN DETERMINANTS OF FERTILITY DECLINE AND AGE-SPECIFIC FERTILITY CURVES

4.1 Introduction

Fertility decline is often viewed and analyzed as a decline in the cumulative level of fertility, measured by the total fertility rate (TFR). For fertility to decline there must be some reduction of fertility at specific ages - fertility must decline for some age groups or else across all age groups concurrently in order to see a cumulative decline. Knodel (1977) described the general age-specific pattern of fertility decline commonly associated with demographic transition, based predominantly on European and Asian declines: fertility declines first at later ages and then a decline in fertility at earlier ages follows. Hirschman (1985) updates this model, suggesting two types of decline. First, a decline in fertility at early ages related to delay in the onset of childbearing in places with high early fertility and universal marriage. Second, declines that begin in middle or later years of childbearing, such as seen in Europe. Generally determinants of fertility decline are hypothesized to encourage declines at specific ages as a result of the mechanisms by which these determinants exert influence on fertility. Using the reduced parameterization of age-specific fertility developed in Chapter 3, this paper seeks to examine the association of determinants of fertility with age-specific fertility curves. This analysis will test hypotheses regarding how determinants of fertility decline may be associated with age-specific fertility.

African Exceptionalism Caldwell and Caldwell (1987) introduce the idea that African fertility decline is fundamentally different from fertility decline elsewhere and that the transition in sub-Saharan Africa (SSA) will not look the same and is not the same as the transition seen in the West, Latin America and Asia; the authors attribute the slower, distinct SSA decline largely to religion, arguing that in Africa "lineage-based systems are so coherent that they will offer greater resistance to the successes of family planning programs than has been encountered elsewhere" (Caldwell and Caldwell, 1987). In fact, Caldwell and Caldwell (1987) argue that fertility in SSA is high in spite of severe constraints to fertility in many African contexts, such as the taboo on pre-marital fertility, lengthy postpartum abstinence, and terminal female abstinence once women become grandmothers. These constraints are overcome by polygyny, widow remarriage, and an emphasis on the desire for conception (Caldwell and Caldwell, 1987). Caldwell et al. (1992) concede that fertility decline had begun in SSA by 1990, but that SSA fertility is high because: SSA remains much less developed than South Asia; the importance of ancestry and descent leads to economic returns for high fertility; polygyny, bride wealth and reproductive decision-making remove the decision making (done by men) from the economic burden (carried by women); communal land distribution and labor-intensive production mean more people, more economic benefit; and there is nearly no family planning, largely due to a lack of political will. These factors will also make the SSA transition different from the Asian transition: there are major differences in constraints on premarital and extramarital sexuality; differences in marital stability; and different emphases on the need and reasons for birth spacing. Fundamentally, Caldwell et al. (1992) argue the SSA decline will be different because contraception use and fertility decline will be similar across all ages, compared to declines elsewhere in which decline began at age 25 and older, increasing with age with the largest decline after age 40. The SSA declines will be characterized by fertility declines at all ages, both within and outside of marriage (Caldwell et al., 1992).

Moultrie et al. (2012) build on this theory using Demographic and Health Survey (DHS) data from 24 SSA countries to look at birth interval dynamics from 1986 through 2010. Their analysis showed a wide variety in birth interval trajectories, but all have been widening since the 1970s, with the widest birth intervals in South Africa and Namibia (about four years). Birth intervals have widened in most countries with lower fertility and higher contraceptive prevalence, but the trend of interval lengthening has been consistent and largely independent of the woman's age and parity. While historical data related to birth intervals is not immediately available to determine whether this effect is different from other transitions, the finding that intervals are lengthening at all ages and parities lends support to the Caldwell et al. (1992) argument that the decline will occur at all ages rather than at later ages first (Moultrie et al., 2012). Bongaarts and Casterline (2013), however, did not find evidence of a different sort of transition in SSA than other regions in their examination of age-specific fertility rates from 1990 through 2010.

The straightforward hypotheses from the theory of African exceptionalism are: *1) SSA will not see changes to its age-specific fertility curve, only overall fertility level; and 2) SSA will perform differently from other regions*, as its relationships between determinants of fertility and fertility are influenced by SSA's exceptionalism.

Mortality Integral to demographic transition theory is the idea that reductions in mortality, particularly infant and child mortality, lead to reduction in fertility (Notestein, 1945). Davis (1963) argued that declining IMR leads to stopping behaviors. Ample empirical evidence has found an association between mortality improvements and reduction in fertility (for example, see Casterline, 2001; Shapiro, 2012; Magadi and Agwanda, 2010). The hypothesis is that *lower mortality is associated with lower fertility and lower mortality is associated with lower fertility at older reproductive ages (stopping).*

Economic Development Economic development is profoundly linked to fertility decline in demographic transition theory, contributing to the start and the pace of fertility decline. Effort has been made to tease out the relationship between socioeconomic development and fertility decline, particularly in light of the slower fertility decline experienced in SSA than that of Latin America and Asia. Bongaarts and Watkins (1996) found that over time there had been a clear reduction in the level of socioeconomic development at the onset of fertility decline, and that while there was no correlation between the rate of change in development indicators and the pace of fertility decline, there was a strong correlation between the pace of decline and level of development at onset. Casterline (2001) found that more rapid improvements in economic development were associated with a more rapid decline in fertility. Bongaarts (2006) found a correlation between development progress and TFR, looking at gross domestic product (GDP) and TFR for 38 countries (using DHS data), and GDP was stalled as well as fertility in Ghana and Kenya. Shapiro and Gebreselassie (2009) using DHS data from the 1980s found that fertility decline was slower when economic growth was more rapid. Bryant (2007) concedes that development indicators are not a direct measure of the sophisticated conceptualizations of how fertility is related to socioeconomic development, though finds, along the lines of Bongaarts (2002), that while the onset of fertility decline and socioeconomic indicators are not well correlated, once the demographic transition is underway they are. Garenne (2009) looked at GDP based on purchasing power parity (PPP) in constant USD, educational attainment, labor force participation and the DHS wealth index to assess income, rather than relying solely on GDP, and notes that from 1950-75, GDP increased while fertility increased in SSA and that GDP was not correlated with trends in the wealth index or poverty from DHS measures. Garenne (2009) concludes, in fact, that "the diversity of situations makes any generalization impossible" in regards to the relationship between economic development and stalls in SSA fertility decline.

The general hypothesis is simply that *more developed contexts will have lower overall fer-*

tility, but understanding the effect of development on age-specific fertility is more complex and depends on the mechanism by which development is hypothesized to impact fertility. Central to most economic theories of demographic transition is the idea that economic development brings about family size limitation and a conscious choice to have fewer children, which would suggest *lower fertility at older ages* through earlier stopping. Theoretical explanations of fertility decline in the most recent decades in the West and East Asia, seeking to explain the lowest low fertility with the personal choices of couples to have one or two children timed according to their desires (Lesthaeghe, 2010) would would suggest that *fertility curves would be more peaked at higher levels of development*, as fertility became more concentrated in fewer reproductive ages.

HIV In countries with high prevalence of HIV, HIV has altered the population and its dynamics profoundly, with massive mortality and morbidity impacting fertility by altering population composition as well as affecting reproductive behavior and biological reproduction. However, research is far from conclusive about how high HIV prevalence may be effecting fertility. HIV can be associated with lower fertility due to reduced coital frequency and sexually transmitted infection co-infection associated with pelvic inflammatory disease and increased fetal loss. HIV is hypothesized to influence many of the proximate determinants of fertility, both to increase and decrease fertility. HIV may reduce fertility by delaying onset of sexual relations and age at first union; reducing premarital sex and remarriage; increasing marriage dissolution and spousal separation; increasing condom use; increasing postpartum ammenorhea; reducing pregnancy rates and increase fetal loss; increasing STI prevalence; and reducing frequency of intercourse and reduce sperm production. Alternatively, HIV may be associated with higher fertility through reduced breastfeeding; reduced postpartum abstinence, and increased infant mortality resulting in child replacement. HIV may reduce desired fertility (Magadi and Agwanda, 2010). In Kenya, HIV-positive women had a about a 40% lower odds of a recent birth than HIV-negative women, but there was no evidence of an association between community level HIV prevalence and fertility (Magadi and Agwanda, 2010). HIV may serve to increase fertility, as perceived HIV risk may shift contraceptive method mix to less effective methods, condoms, as part of dual-use strategies, and roll-out of prevention of mother-to-child transmission (PMTCT) of HIV has enabled HIV positive women to have HIV-free children in more recent years (Moultrie et al., 2008). Juhn et al. (2013), however, found that HIV prevalence in a community has a somewhat depressing effect on fertility, though this is not analyzed in consideration of pre-HIV fertility trends. Gregson et al. (2002) argue that HIV infection is facilitated by increased urbanization, secularization, and economic development and that the effect of the HIV epidemic on fertility is in part determined by the point in the transition when the epidemic hits. The authors argue that there is some increased fertility as a response to increased mortality, both acting as insurance and replacement. In a population-based cohort of over 3500 women in rural southwest Uganda followed for over seven years, fertility rates were lower for HIV-postive women except at the lowest age groups (15-19 years) (Carpenter et al., 1997). For Kenya, HIV was associated with a halt in the reduction of desired family size due to increased child mortality (Westoff and Cross, 2006). Garenne (2011) indicated that high HIV prevalence could lead to overestimation of fertility, since fertility is measured retrospectively and HIV-positive women who died, and have lower total fertility, are missing from the data. Evidence from rural South Africa found that fertility decline stalled at the height of the HIV epidemic but that the decline continued once antiretrovirals were rolled out (Houle et al., 2016). The theory and evidence suggest contradictory effects of HIV on fertility, making it challenging to elaborate an explicit hypothesis regarding this relationship except the broad hypothesis that *HIV prevalence is associated with fertility level and age-specific fertility.*

Women's Education Education is commonly analyzed in association with fertility decline, and low levels of education among women have been linked to slow or stalled fertility decline. Fertility differentials across education are persistent over time and place. In East

Africa, Ezeh et al. (2009) found an association between education level and fertility stalls at the sub-national level. In Kenya, the most pronounced stall in fertility was among the least educated, and, in fact, women with secondary or higher education actually continued to experience declines in fertility (Westoff and Cross, 2006). Female empowerment is often discussed, generally in tandem with female education, as a crucial factor contributing to fertility decline. Often women's educational attainment is used as a proxy measure for female empowerment. McDonald (2000) suggests that understanding gender relations that are present during the decline are important for understanding pace of decline. High fertility is socially determined and the transition from high to low fertility is accompanied by an increase in gender equity within the family, which has a major effect on women's lives (McDonald, 2000). Shapiro (2012), using DHS data for 28 SSA countries with surveys since 2000, found a broad negative correlation between women's education and fertility for the world and also for SSA. Countries with an increasing proportion of women with higher levels of education saw faster fertility decline, and at the level of the individual woman, a woman was less likely to have more children the higher her level of education, with the effect increasing with increased education. This work suggests that we would expect women's education to have a direct, measurable effect on the age-specific fertility curve. The primary mechanism suggested in the literature is through stopping behavior. Another potential effect of increased women's education or empowerment may be delayed initiation of fertility through later marriage (Hirschman, 1985), suggesting lower fertility at early ages. *The hypothesis would be that higher levels of women's education are associated with lower fertility levels; lower fertility at late ages; and lower fertility at early ages.* This could also suggest higher levels of women's education are associated with fertility concentrated in fewer ages. However, Johnson-Hanks (2004) found that variability in birth intervals (i.e. spacing and also stopping, potentially) increases as women's education increases in Cameroon, suggesting that at least in some contexts the relationship between education (or empowerment measures) may be weaker than expected.

Contraceptive Use Contraception use has long been integral to explanations of fertility decline, being among the proximate determinants of fertility (Bongaarts, 1978). Contraception may be used in any number of ways: for stopping, which would reduce fertility at older ages; to delay childbearing, which would reduce fertility in early ages; to extend birth intervals, which may not affect the age-specific fertility curve at all; or to replace other means of family planning, which would not change the age-specific fertility curve. Caldwell et al. (1992) argued that high contraception use in SSA was not necessarily associated with declines in fertility because: strong demand for spacing due to the traditionally long birth intervals being shortened as traditional postpartum abstinence declines; and demand for contraception in later years as an alternative to terminal abstinence. Bledsoe et al. (1998), however, found that women in the Gambia did not use contraception to reduce fertility at all but to support existing fertility practices, such as long birth intervals for recovery between births. The general hypothesis is *high contraception use will be associated with lower fertility*, though it the literature does not suggest that high contraception use will be associated with changes to the age-specific fertility curve.

Urbanization Urbanization is frequently associated with lower fertility, though this relationship has not been found to be as consistent outside of the West (Jaffe, 1942; Robinson, 1963). Lower urban fertility is generally explained in part through the effects of migration (including selection and spousal separation or "disruption") and the effects of modernization and Westernization associated with urban living that suppress fertility and to which migrants also adapt (White et al., 2005). Fertility differs greatly between urban and rural areas in SSA. Shapiro and Gebreselassie (2009) found living in an urban area was associated with lower fertility across countries experiencing stalls or slow fertility decline. Analyzing the urban-rural gaps in fertility in the proposed stalling countries, Machiyama (2010) found that over 15 years the gap between urban and rural TFR was widening for Benin, Cameroon, Nigeria, Tanzania and Zambia, while the gap in Ghana and Uganda widened until 2000 after which it was constant and the gap in Kenya was nearly constant while Rwanda's gap narrowed, suggesting a wide variation in the relationship between fertility decline and urbanization. The first hypothesis is that *higher levels of urbanization are associated with lower fertility*. Hirschman (1985) argued that urbanization leads to late marriage and later first birth, suggesting urbanization would be associated with a decline in early age fertility. The second hypothesis is that *higher levels of urbanization are associated with lower fertility in early ages.*

4.2 Data

Global age-specific fertility rate data from 1950-55 through 2005-10, as well as total fertility rate, infant and child mortality, life expectancy and child survival data were obtained from the UN's World Population Prospects (WPP) 2012 Revision (United Nations, 2013). UN WPP data are provided for all countries in five year intervals from 1950-55 to 2005-10 for five year age groups (ages 15-19 to ages 45-49). Countries with a population of at least one million were included in the analysis, and three countries with unique TFR trajectories over the time under study were excluded (Yemen, Gabon and Timor-Leste); 154 countries were included in the final analysis. Data from the UN WPP are the most complete data available for global fertility and provide data for 50 years for all countries in the world, despite the fact that these data are already processed, and to an extent, smoothed by the UN. These same data have been used in comparative analyses of fertility trends elsewhere as well (e.g. Dorius, 2008; Bryant, 2007; Wilson, 2001; Casterline, 2001), largely due to their global coverage and their use for making population projections. Data for infant mortality rate (per 1,000 live births), under five mortality rate (per 1,000 live births) and life expectancy at birth also come from the UN WPP data, providing data for the included 154 countries from 1950-55 through 2005-2010. These mortality measures are for both sexes combined.

Gini coefficient, women's labor force participation, female literacy rate, proportion of women with any schooling, and women's educational attainment were obtained from the World Bank Development Indicators (World Bank, 2014). Per capita GDP was taken from the Maddison Project 2013 revision (The Maddison Project, 2013). These data cover 133 countries from 1950-55 to 1985-90 and 150 countries from 1990-95 to 2005-10 and provide historical GDP for all countries of the world based on estimates and best available data. Per capita GDP data represent five year averages. The Gini coefficient, from the World Bank, is only available from 1985 through 2005, and for a smaller subset of countries (71 to 112 countries). Women's labor force participation is available for 152 countries from 1990 through 2005. The female literacy rate is available for a variable subset of countries (20 to 118) from 1975 to 2005. The proportion of women with any schooling and women's educational attainment were available fro 131 countries from 1970 through 2005. The Human Development Index (HDI) was obtained from the United Nations Development Program Human Development Index program (UNDP, 2015) and had data for 1980 through 2010 at five year intervals for up to 147 (and at least 113) countries in our dataset. HIV prevalence data for all adults, young women age 15-24, and adult women (age 15-49) were obtained from UNAIDS and cover the period 1990 through 2005. More recent HIV data is available but fertility data ends in 2005-10. Eighty-nine countries have data available through UNAIDS for adult prevalence measures. Data for family planning indicators are from the United Nations Millennium Development Goals indicator database (United Nations, 2015a) and only cover from 1990 through 2005. Not all countries are represented in the data, with many only providing data in the last years, 104 for unmet family planning need and 149 for contraceptive prevalence rate (CPR). Urbanization data comes from the UN 2014 Revision of World Urbanization Prospects (United Nations, 2015c) and covers 1950-1955 through 2005-2010 for all 154 included countries.

4.3 Methods

Outcome Measures The outcome measures used in this analysis are results from the singular value decomposition (SVD) analysis on the age-specific fertility rates for each country and time period, described in detail in Chapter 3. Age-specific fertility rates for 1,848 country-periods were analyzed to retain three components (out of a total of six obtained from the SVD) that describe age-specific fertility curves. Weights on the three components, referred to as v_1, v_2 and v_3 from the SVD notation, describe the composition of age-specific fertility along the three independent dimensions identified by the SVD, see Chapter 3. These weights provide the parameterization of the age-specific fertility curve as they encode the underlying level of fertility, v_1; the balance between younger and older ages, v_2; and the degree of concentration of the fertility at central age groups, v_3. Figure 4.1 shows how variation in the weights alters the curves. As v_1 increases overall fertility declines. While the shape of the curve remains constant, the area under it shrinks. At lower values of v_1 the curve is shifted higher resulting in more area under the curve and higher overall fertility. Alternatively, one can imagine that for lower values of v_1, fertility increases at all ages. At low values of v_2 fertility increases at early ages and fertility decreases at later ages, shifting peak fertility to earlier ages. At higher values of v_2, fertility is lower at early ages and fertility is higher at later ages, shifting peak fertility to later ages. Lower values of v_3 result in a sharp peak in fertility in the middle reproductive ages. This represents a concentration of fertility in the late 20s and early 30s. High values of v_3 create a flat curve where fertility is more evenly spread across all ages. Note that in Figure 4.1 changes to v_2 and v_3 these curves are constrained to maintain the median overall fertility level - the effects here are exaggerated because age-specific fertility must add up to the median, which is effectively being dictated by having given the median value of v_1.

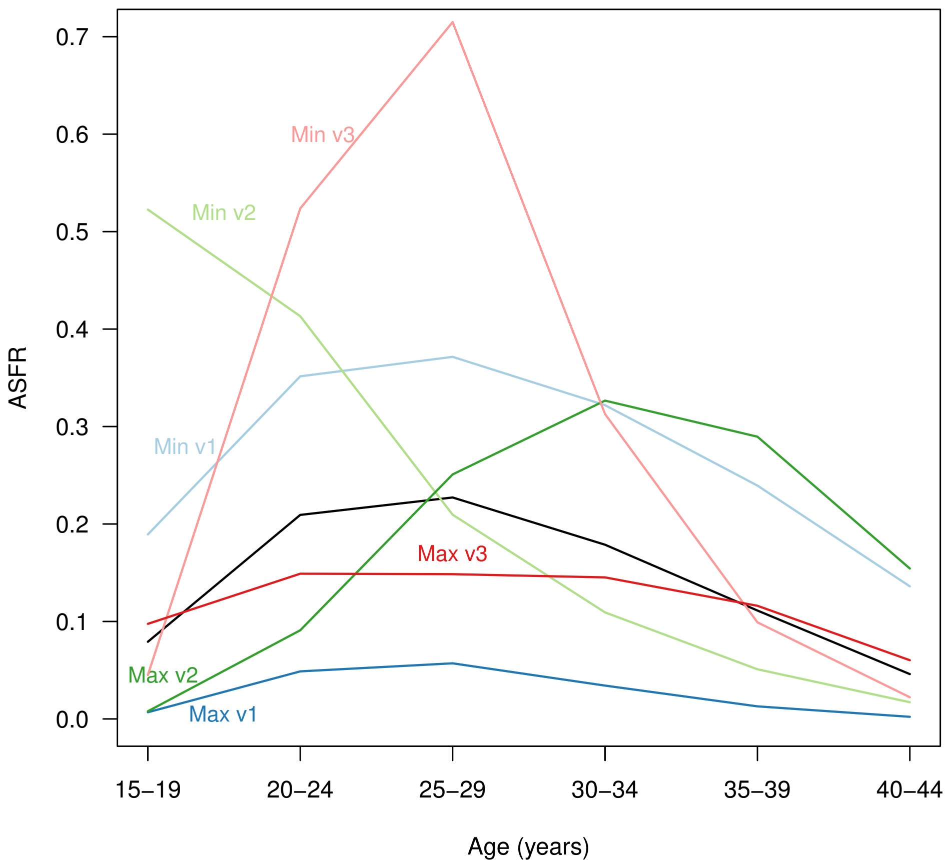

Figure 4.1: Median reconstructed age-specific fertility curve with curve resulting from the maximum and minimum of each weight shown. The curves resulting from using the maximum and minimum values of v_1 while holding all other weights at the median are shown in blue, dark and light respectively. The curves resulting from using the maximum and minimum values of v_2 while holding all other weights at the median are shown in dark and light green, respectively. The curves resulting from using the maximum and minimum values of v_3 while holding all other weights at the median values are shown in dark and light red, respectively. The median fertility curve is shown in black.

Hypotheses Restated The hypothesized relationships between different factors and age-specific fertility presented in the earlier section can be best understood now in terms of the weights that will be used as outcome measures.

- Mortality
  - Improvements in mortality will be associated with a decline in overall fertility, meaning *lower mortality will be associated with higher values of* v_1.
  - Improvements in mortality will be associated with lower fertility at older reproductive ages (stopping), meaning that *lower mortality will be associated with lower values of* v_2.
- Development
  - More developed contexts will have lower overall fertility suggests that *higher measures of development will be associated with higher values of* v_1.
  - More developed contexts will have lower fertility at older ages, meaning *higher measures of development will be associated with lower values of* v_2.
  - Fertility curves would be more peaked at higher levels of development; *higher measures of development will be associated with lower values of* v_3.
- HIV: the theory and evidence regarding HIV is too contradictory to establish clear hypotheses to test beyond the general hypothesis that *HIV prevalence will be associated with* v_1, v_2 *and* v_3.
- Women's Education
  - Increased women's education would be associated with lower fertility: *higher levels of women's education will be associated with higher values of* v_1.

  - Increased women's education would be associated with lower fertility at late ages: *higher levels of women's education will be associated with lower values of* v_2.
  - Increased women's education would be associated with lower fertility at early ages: *higher levels of women's education will be associated with higher values of* v_2

- Contraception: high contraception use will be associated with lower fertility, meaning *high contraception use will be associated with higher values of* v_1.

- Urbanization
  - Higher levels of urbanization will be associated with lower fertility: *higher levels of urbanization will be associated with higher values of* v_1.
  - Higher levels of urbanization will be associated with lower fertility in early ages: *higher levels of urbanization will be associated with higher values of* v_2.

Analytic Approach The inconsistencies in temporal and geographic coverage of the data are substantial and have required consideration in the development of the analysis plan. First, these factors are tested individually, running pooled OLS regressions on each weight for each factor, controlling for geographic region and year and with robust standard errors clustered on country. Six geographic regions were used: sub-Saharan Africa (SSA); East Africa; Central and South Asia including Oceania (referred to as South Asia); Latin America and the Caribbean (LAC); Europe, the United States, Canada, Australia and New Zealand (abbreviated as the West); and the Middle East and North Africa (MENA). These models provide initial tests of the hypothesized relationships between these factors and age-specific fertility.

Multivariate models were explored for each weight separately, however, data availability greatly constrained the sample size for these models. To deal with this, initial models started with variables that would maximize sample size and other factors were added one by one. Final models, shown and discussed here, were those models that performed the best taking into account data availability and the sample size. In the case of the third weight, there were interesting results with two variables that were only available for few years (HIV prevalence and the Gini coefficient) and these are also shown.

Both individual factor and multivariate models showed strong regional effects. To examine these effects, first the multivariate models were run stratified by region. These models displayed such variability across region that multilevel models were run to capture the regional variation.

4.4 Results

4.4.1 Individual Factors

Regressions were run to examine each factor's relationship with each weight in isolation from other factors. These models did, however, control for secular trends and for region. There were significant secular trends and regional associations present in all models. These relationships are investigated and discussed in subsequent results and this section focuses solely on the association seen with the individual factors. Results are presented in Table 4.1.

Mortality Two measures of mortality were examined: infant mortality rate and life expectancy at birth. Both measures have distinct relationships with TFR with regional patterning. This relationship bore out when investigating their relationship with the weights. In both cases there was a strong correlation between the mortality measure and v_1. However, no relationship was detected between either mortality measure and v_2 or v_3 once regional patterns and secular trends were controlled for. As expected, IMR has a negative association with v_1 which indicates that as IMR decreases (improves) fertility decreases as well. Also as expected, life expectancy at birth has a positive association with v_1, meaning that as life expectancy increases there is a decline in fertility. In neither case does mortality seem to be associated with the shape of the fertility curve, indicating that changes in mortality are only associated with changes in fertility level.

Economic Development Three measures of economic development were investigated. Logged GDP, Gini coefficient and HDI are all commonly used in the literature to look at the effects of economic development on fertility. When modeling the weights, and thus separating the fertility level from some aspects of the age patterns, these indicators appear to have different relationships with fertility. Logged GDP behaves as anticipated generally, with a significant positive relationship with v_1, indicating that increases in GDP are associated with declines in fertility. However, there appears to be no relationship between GDP and the shape of the fertility curve. Gini coefficient, however, measuring economic inequality in a population, does not seem to have a relationship with overall fertility level, but has a significant, positive relationship with v_3, indicating that higher inequality is associated with a flatter fertility curve, meaning that fertility is spread more evenly across all ages in countries with higher levels of inequality. HDI, like GDP, has a significant, positive association with v_1, indicating that higher levels of development are associated with lower overall fertility. HDI also has a positive relationship with v_2, which suggests that higher levels of development are associated with lower fertility at younger ages and higher fertility at older ages.

HIV HIV prevalence was found to be positively associated with both v_1 and v_3. Higher HIV prevalence in a population was associated with lower fertility, though this should be noted that this was in a subset of 89 countries with reported HIV prevalence, for which higher prevalence countries were more likely to have reported HIV prevalence than countries with very low HIV prevalence. The positive relationship with v_3 indicates that higher HIV prevalence is associated with flatter age-specific fertility curves.

Women's Empowerment Women's empowerment is often measured with women's education or women's workforce participation. Four measures were examined here: female labor force participation; female literacy rate; women's educational attainment at age 25 or older, and the proportion of women with any school. Data coverage varied across these measures. All four measures had a positive relationship with v_1, as anticipated, with higher levels of women's labor force participation, women's literacy and women's education associated with lower fertility. Female labor force participation was also negatively associated with v_2, indicating that higher levels of female labor force participation were associated with lower levels of fertility at later reproductive ages. This association likely reflects earlier stopping, or overall family limitation. This same relationship is evident for the proportion of women with any schooling. Female literacy, female educational attainment and the proportion of women with any schooling were all negatively associated with v_3, indicating that as these measures increased the age-specific fertility curve had a sharper peak. Thus, when more women were literate, or more women were educated, or women had higher education on average, fertility was more concentrated in a narrower range of ages. The proportion of women with any schooling performed consistently like other measures and had the most data available so is used in subsequent models. However, there is some regional patterning to performance across these four variables and a composite score was investigated for use in these models. Data limitations meant that a composite score would only be available for a very, very small subset of country-periods and would exclude most Western countries so was not used. Appendix C presents the composite measure.

Contraception Two commonly used measures related to contraception use were tested: CPR and unmet family planning need. The sample with data for these measures was quite limited. CPR was positively associated with v_1, indicating that higher levels of CPR are associated with lower levels of fertility, as one would expect. There was no relationship with other weights, indicating that contraceptive use was associated, in general, with lower fertility over all ages. Unmet family planning need was negatively associated with v_1, indicating that higher unmet family planning need was associated with higher fertility, as one would expect. Unmet family planning need was also associated positively with v_2, indicating that where unmet family planning need was higher, fertility was higher in older reproductive ages, possibly related to women not able to use family planning for family limitation or for birth spacing. This finding is consistent with how Bledsoe et al. (1998) found contraception to be used in SSA.

Urbanization Proportion urban was used to examine the relationship between urbanization and fertility. There was a significant positive association between proportion urban and v_1, indicating when more of a population lived in urban areas there was lower overall fertility. No relationship was found with the weights associated with the shape of the fertility curve.

4.4.2 Multivariate Analysis

Data availability greatly constrained the population on which it was possible to run multivariate models and the long time series and global coverage was quickly lost with the inclusion of some factors. Due to this limitation, the initial models considered were those with covariates that preserved the longest time series and the most coverage: IMR or life expectancy (available for all); urbanization (available for all); logged GDP (133 countries 1950-55 through 1985-90 and 150 countries 1990-95 through 2005-10); and the proportion of women with any schooling (131 countries 1970-75 through 2005-10). Then additional factors were added to the model one by one. The final models presented here in Table 4.2 included the factors that were consistently significant and retained the majority of the sample. Some additional models with small samples are also discussed below.

v_1 Modeling the weight on the first component, the best model included life expectancy as a measure of mortality, logged GDP and women with any schooling. Additional factors were

Table 4.1: Simple Regression Results

	v_1	v_2	v_3	n
IMR	-.0024 (.0003)**	-.0009 (.0018)	.0011 (.0020)	1848
Life Expectancy at Birth	.0031 (.0004)**	.0026 (.0021)	-.0036 (.0019)	1848
Logged GDP	.0024 (.0004)**	.0023 (.0021)	-.0009 (.0024)	1664
Gini coefficient	.0002 (.0004)	.0030 (.0027)	.0069 (.0016)**	481
Human Development Index	.0035 (.0004)**	.0060 (.0028)*	-.00125 (.0022)	766
HIV Prevalence	.0006 (.0002)*	-.0010 (.0009)	.0023 (.0009)*	356
Female Labor Force Participation	.0012 (.0004)**	-.0066 (.0025)**	-.0030 (.0016)	608
Female Literacy Rate	.0025 (.0003)**	-.0022 (.0026)	-.0045 (.0020)*	460
Female Educational Attainment	.0032 (.0004)**	-.0032 (.0025)	-.0055 (.0021)*	917
Women with Any Schooling	.0032 (.0003)**	-.0054 (.0022)*	-.0050 (.0017)**	1048
CPR	.0021 (.0004)**	.0005 (.0026)	.0021 (.0020)	500
Unmet Family Planning Need	-.00184 (.00049)**	.0061 (.0024)*	.0016 (.0014)	312
Proportion Urban	.0016 (.0003)**	.0024 (.0015)	-.0006 (.0017)	1848

Coefficient (standard error) for each factor from pooled ordinary least squares regressions controlling for region and year on each weight. Standard errors are robust, clustered by country. A */** next to coefficient indicates significance at the 5/1% level.

not significant predictors of the first weight and further restricted the sample. This model explained a substantial amount of the variation in overall fertility level. Life expectancy, logged per capita GDP, and the proportion of women with any schooling had a positive relationship with v_1, as expected, showing that with longer life expectancy, higher per capita GDP, and more women receiving some schooling, fertility is lower. Other measures of women's empowerment performed similarly to the proportion of women with any schooling, and this variable had the most available data. Regional effects were strong here, with all regions but East Asia having a significant negative association with v_1, indicating that these regions all experience higher fertility than the West, the reference category. The secular trend in v_1 is quite strong, with lower fertility associated with later years, using 1970-75 as the reference year.

v_2 The final model for the weight on the second component included logged per capita GDP and the proportion of women with any schooling. Mortality did not have an effect on v_2 in multivariate models. Logged GDP had a positive relationship with v_2; higher GDP is associated with lower fertility at younger ages, suggesting a delay in the onset of childbearing. HDI performed similarly to GDP but GDP was retained because of greater data availability. Women's education, however, was negatively associated with v_2; when more women have some exposure to education, there is lower fertility at later reproductive ages. There are strong regional effects for v_2, with all but Latin America and the Caribbean having significantly different relationships with v_2 than the West, indicating that all these regions were more likely to have higher fertility at later ages than the West. The secular trend for v_2 is not nearly as strong as the one seen for v_1, though there does appear to be evidence of a general movement towards higher fertility at later ages in the last decade under analysis.

v_3 None of the variables for which there was substantial coverage were significant predictors of v_3 in the multivariate model, and the best fitting model only included variables for the region and year. This model was still able to describe a substantial portion of the variation in v_3. There was a strong regional effect, with all regions but East Asia having flatter curves than the curve seen in the West (higher v_3 corresponds to flatter age-specific fertility curves, or curves where fertility is more evenly distributed across ages). East Asia has has a more peaked curve than the West, making it the most peaked of all the regions; in East Asian curves, fertility is highly concentrated in few reproductive ages compared to other regions. The secular effect was strong for early years, suggesting a trend towards more peaked curves from 1955-60 through 1970-75. Later years have a significant effect in the opposite direction, suggesting that since the 1990s the trend was towards flatter curves, where fertility is less concentrated in particular ages (relative to 1950-55).

Though the resulting sample is quite small, v_3 had a significant relationship with both HIV prevalence and the Gini coefficient. These models are shown in Table 4.3. Higher HIV prevalence was associated with a flatter curve, even when controlling for region and secular trends. Gini coefficient was positively correlated with v_3 as well, indicating that higher levels of economic inequality are associated with flatter fertility curves, or that fertility is spread out relatively evenly across the reproductive ages.

Table 4.2: Multivariate Regression for the Component Weights.

	v_1	v_2	v_3
Life Expectancy	0.0015(0.0005)**	*not included*	*not included*
Logged GDP	0.0011(0.0005)*	0.009(0.0028)**	*not included*
Women with Any Schooling	0.0019(0.0004)**	-0.009(0.0027)**	*not included*
West	*reference*	*reference*	*reference*
SSA	-0.0069(0.0011)**	0.0139(0.0065)*	0.0280 (0.0026)**
East Asia	0.0018(0.0016)	0.0295(0.0054)**	-0.0286 (0.0110)**
South Asia	-0.0043(0.001)**	0.015 (0.007)*	0.0094 (0.0041)**
LAC	-0.0068(0.0007)**	-0.0007(0.0047)	0.0260 (0.0025)**
MENA	-0.0062(0.0008)**	0.0191(0.0075)*	0.0067 (0.0039)
1950-55			*reference*
1955-60			-0.0020 (0.0005)**
1960-65			-0.0033 (0.0007)**
1965-70			-0.0024 (0.0010)*
1970-75	*reference*	*reference*	-0.0027 (0.0013)*
1975-80	0.0006 (0.0001)**	-0.0012(0.0006)*	-0.0026 (0.0014)
1980-85	0.0010 (0.0002)**	0.0002(0.001)	-0.0030 (0.0016)
1985-90	0.0015 (0.0003)**	0.0031(0.0017)	-0.0016 (0.0019)
1990-95	0.0022 (0.0003)**	0.0023(0.0023)	0.0035 (0.0020)
1995-00	0.0028 (0.0004)**	0.0055(0.0028)	0.0084 (0.0019)**
2000-05	0.0029 (0.0004)**	0.0087(0.0032)**	0.0117 (0.0019)**
2005-10	0.0026 (0.0005)**	0.011(0.0035)**	0.0122 (0.0020)**
Intercept	0.0068 (0.0041)	-0.014(0.0048)***	0.0168 (0.0018)**
N	984	984	1848
R^2	0.8705	0.2711	0.4412

Coefficient (standard error) for each factor from pooled ordinary least squares regressions controlling for region and year on each weight. Standard errors are robust, clustered by country. A */** next to coefficient indicates significance at the 5/1% level.

Table 4.3: Alternative Multivariate Models for v_3.

	HIV	Gini Coefficient
HIV Prevalence	0.0023(0.0009)*	
Gini Coefficient		0.0069(0.0016)**
West	*reference*	
SSA	0.0162 (0.0039)**	0.01160 (0.00412)**
East Asia	*no data*	-0.04000 (0.01991)*
South Asia	0.0066 (0.0051)	0.00243 (0.00486)
LAC	0.0254 (0.0039)**	0.01558 (0.00457)**
MENA	0.0068 (0.0094)	0.01558 (0.00457)
1985-90		*reference*
1990-95	*reference*	0.007 (0.001)**
1995-00	0.0021 (0.0007)**	0.011 (0.002)**
2000-05	0.0029 (0.0011)**	0.014 (0.002)**
2005-10	0.0019 (0.0013)	0.015 (0.002)**
Intercept	0.0030 (0.0034)	-0.033 (0.005)
N	356	481
R^2	0.2636	0.4936

Coefficient (standard error) from pooled ordinary least squares regressions on each weight. Standard errors are robust, clustered by country. A */** next to coefficient indicates significance at the 5/1% level.

4.4.3 African Exceptionalism

In all the foregoing models region was treated as a categorical variable and a dummy was included for SSA. In each of these models the reference category was the West, chosen as the referent because this was the region on which demographic transition theory was originally based. Looking at the multivariate models (shown in Table 4.2), SSA was significantly different from the West for all three parameters: significantly different overall level (v_1), significantly different balance between early and late fertility (v_2), and significantly different flatness of the curve (v_3). However, SSA was not the only region significantly different from the West across the parameters. South Asia was also different across all three parameters, while Latin America and the Caribbean was significantly different from the West in overall level and the flatness of curves, East Asia differed from the West in terms of the balance between early and late fertility and in flatness of curve and the Middle East and North Africa differed in overall level and the balance between early and late fertility.

For the models where each factor was tested alone with region and year, SSA was significantly different from other regions for all models for v_1 except life expectancy. For v_2, however, SSA was only significantly different from other world regions in models that included the Gini coefficient and HIV. Modeling v_3, SSA was significantly different from other regions for most models but was not for the models with Gini coefficient, HDI, adult HIV prevalence, or unmet family planning need as covariates. When only the SSA dummy was included (Table 4.4), SSA was significantly different from non-SSA regions for models for v_1 and v_3 though not significantly different for v_2.

4.4.4 Stratified Analysis

Given the strong regional effects seen for all the weights, multivariate models stratified by region were run. Results are shown in Table 4.5, Table 4.6 and Table 4.7 for v_1, v_2 and v_3 respectively.

Table 4.4: Models Comparing Sub-Saharan Africa to all Other Regions

	v_1	v_2	v_3
SSA	-0.0083(0.0006)**	0.0026(0.2695)	0.021(0.0023)**
1950-55		*reference category*	
1955-60	0.0001(0.0001)	-0.0012(0.0004)**	-0.002(0.0005)**
1960-65	0.0002(0.0001)	-0.0019(0.0007)**	-0.0033(0.0007)**
1965-70	0.0007(0.0001)**	-0.0035(0.0009)**	-0.0024(0.001)*
1970-75	0.0014(0.0002)**	-0.0058(0.0013)**	-0.0027(0.0013)*
1975-80	0.0024(0.0003)**	-0.0084(0.0015)**	-0.0026(0.0014)
1980-85	0.0033(0.0003)**	-0.0089(0.0017)**	-0.003(0.0016)
1985-90	0.004(0.0003)**	-0.0084(0.0018)**	-0.0016(0.0019)
1990-95	0.0049(0.0003)**	-0.0085(0.002)**	0.0035(0.002)
1995-00	0.0059(0.0004)**	-0.0063(0.0021)**	0.0084(0.0019)**
2000-05	0.0066(0.0004)**	-0.0032(0.002)	0.0117(0.0019)**
2005-10	0.0069(0.0004)**	-0.0005(0.0021)	0.0122(0.002)**
N	1848	1848	1848
R2	0.4215	0.022	0.2225

Coefficient (standard error) for each factor from pooled ordinary least squares regressions on each weight. Standard errors are robust, clustered by country. A */** next to coefficient indicates significance at the 5/1% level.

v_1 First, the effect for life expectancy disappears in all regional models for v_1, suggesting that this relationship is only seen at the aggregate and not evident in the models with smaller sample size. Logged GDP retains a significant positive association with v_1 only for SSA and South Asia, suggesting that increased development was not having an impact on fertility level in other regions from 1970 on. Women's education, measured as the proportion of women with any schooling retained its significant relationship with v_1 in SSA, Latin America and the Caribbean, the West, and the Middle East and North Africa. In East and South Asia, increased women's education was not associated with lower fertility. The secular trend is notably strongest in the West. The effect of year is less patterned in other world regions, though SSA seems to have a strong secular trend since the 1990s, with these years associated with a growing positive association with v_1 and, thus, reduced fertility.

Table 4.5: Regressions on v_1, stratified by region. Coefficient and standard error for each factor from pooled ordinary least squares regressions controlling for year.

	SSA	East Asia	South Asia	LAC	West	MENA
Life Expectancy	0.0003(0.0006)	0.0096(0.0061)	0.0019(0.0011)	0.0024(0.0018)	-0.0016(0.0017)	0.0004(0.0021)
Logged GDP	0.0023(0.0007)**	-0.0004(0.0031)	0.0028(0.001)*	0.0002(0.0015)	0.0002(0.0012)	-0.0007(0.0011)
Women Schooling	0.001(0.0002)**	0.0015(0.0019)	0.0009(0.0009)	0.0025(0.0011)*	0.0024(0.0008)**	0.0038(0.001)**
1970-75			*reference category*			
1975-80	-0.0001(0.0001)	0.002(0.0012)	0.0006(0.0005)	0.0006(0.0002)*	0.0018(0.0003)**	0.0001(0.0007)
1980-85	0(0.0002)	0.0033(0.0029)	0.0008(0.0006)	0.0008(0.0004)*	0.003(0.0005)**	0.0003(0.0009)
1985-90	0.0004(0.0002)	0.0038(0.0041)	0.0011(0.0008)	0.0012(0.0007)	0.0035(0.0005)**	0.0007(0.0014)
1990-95	0.0011(0.0003)**	0.0044(0.0042)	0.0016(0.0009)	0.0017(0.001)	0.0036(0.0006)**	0.0015(0.0017)
1995-00	0.0016(0.0003)**	0.0048(0.0043)	0.0027(0.001)*	0.0023(0.0012)	0.0042(0.0007)**	0.0023(0.0017)
2000-05	0.002(0.0004)**	0.0034(0.0047)	0.0033(0.001)**	0.0028(0.0014)	0.0039(0.0007)**	0.0027(0.0017)
2005-10	0.0023(0.0005)**	0.0013(0.0048)	0.003(0.0011)*	0.0031(0.0014)*	0.003(0.0008)**	0.0028(0.0016)
Intercept	0.0187(0.0012)**	0.0203(0.003)**	0.0214(0.001)**	0.0185(0.0007)**	0.0286(0.0008)**	0.0227(0.0014)**
N	240	40	140	176	256	132
R^2	0.6944	0.8001	0.7768	0.7069	0.3193	0.7302

Coefficient (standard error) from pooled ordinary least squares regressions controlling for year. Standard errors are robust, clustered by country. A */** next to coefficient indicates significance at the 5/1% level.

v_2 From the stratified models it appears that the effect seen for GDP was driven by the relationship seen in the West, where higher GDP is associated with higher v_2, or lower fertility at younger ages. Similarly, the effect of women's education was driven by effects seen in Latin America and the Caribbean and in the West, which both had negative associations between v_2 and women's education, indicating that higher proportions of women with schooling were associated with lower fertility at later reproductive ages, indicating increased stopping. Secular trends were limited to the West and the Middle East and North Africa. The West has seen lower fertility at younger ages since the 1980s, the Middle East and North Africa since the 1970s. The model for SSA, however, has no significant effects and explains virtually none of the variation in v_2.

v_3 Stratifying by region, models show which regions had strong secular trends for v_3 and for which regions secular trends provided minimal information about the variation in v_3. SSA and South Asia, for example, had virtually none of their variation in v_3 explained, while Latin America and the Caribbean saw a strong temporal effect on v_3. Other regions saw some significant year effects.

4.4.5 Random Intercept Models

Results from the random intercept models combine what was seen in the multivariate model with the variation across region seen in the regionally stratified models. Results from the random intercept models are shown in Table 4.8 and the random intercepts by region are shown in Table 4.9 for each model.

For v_1, the relationship with life expectancy, GDP and women's schooling remain strong though the magnitude of the effect of life expectancy has decreased while the magnitude of the effect of the proportion of women with any schooling has increased now that random intercepts are included for each region. SSA, South and Central Asia, Latin America and

Table 4.6: Regressions on v_2, stratified by region. Coefficient and standard error for each factor from pooled ordinary least squares regressions controlling for year.

	SSA	East Asia	South Asia	LAC	West	MENA
Logged GDP	-0.0047(0.0026)	0.0082(0.0035)	0.0034(0.0055)	0.0024(0.0069)	0.0362(0.0059)**	0.0044(0.007)
Women Schooling	0(0.0019)	-0.0005(0.0076)	0.0047(0.0041)	-0.015(0.0066)*	-0.0325(0.0065)**	-0.0144(0.0112)
1970-75			*reference category*			
1975-80	-0.0003(0.0006)	-0.0103(0.0065)	-0.0029(0.0011)*	-0.0023(0.0008)**	-0.005(0.0013)**	0.0041(0.002)
1980-85	0.0001(0.0008)	-0.0188(0.013)	-0.0052(0.0029)	-0.0026(0.0014)	0.0023(0.002)	0.0103(0.0037)*
1985-90	0.0001(0.0012)	-0.021(0.0189)	-0.0067(0.005)	-0.0039(0.0023)	0.0073(0.0025)**	0.0203(0.0068)**
1990-95	-0.0006(0.0016)	-0.0168(0.0152)	-0.0144(0.0067)*	-0.0053(0.0032)	0.0099(0.0036)**	0.0234(0.0086)*
1995-00	-0.0017(0.002)	-0.0151(0.0181)	-0.0161(0.0078)	-0.0074(0.0038)	0.0196(0.0041)**	0.0295(0.0112)*
2000-05	-0.0023(0.0024)	-0.0104(0.0197)	-0.0171(0.0082)*	-0.0067(0.0048)	0.0257(0.0044)**	0.0348(0.0143)*
2005-10	-0.0026(0.0025)	-0.0023(0.0221)	-0.0182(0.0088)	-0.0061(0.005)	0.0298(0.0044)**	0.038(0.0168)*
Intercept	0.0014(0.0024)	0.0273(0.0088)*	0.0198(0.0062)**	-0.0025(0.0037)	-0.0347(0.0085)**	-0.013(0.0193)
N	240	40	140	176	256	132
R^2	0.0691	0.3674	0.1282	0.3941	0.5944	0.1201

Coefficient (standard error) from pooled ordinary least squares regressions controlling for year. Standard errors are robust, clustered by country. A */** next to coefficient indicates significance at the 5/1% level.

Table 4.7: Regressions on v_3, stratified by region. Coefficient and standard error for each factor from pooled ordinary least squares regressions controlling for year.

	SSA	East Asia	South Asia	LAC	West	MENA
1950-55			*reference category*			
1955-60	0.0003(0.0004)	-0.0104(0.0038)*	-0.0017(0.0008)*	-0.0009(0.0009)	-0.0047(0.0014)**	-0.0007(0.0006)
1960-65	-0.0001(0.0008)	-0.0195(0.0066)*	-0.0034(0.002)	-0.001(0.001)	-0.0057(0.0016)**	-0.0025(0.0011)*
1965-70	0.0004(0.0011)	-0.0269(0.0107)	-0.0037(0.0026)	0.0024(0.0015)	-0.0044(0.0023)	-0.001(0.0015)
1970-75	0.0002(0.0012)	-0.0367(0.0101)*	-0.0067(0.0042)	0.0059(0.0024)*	-0.005(0.0027)	0.0005(0.0022)
1975-80	0.0009(0.0013)	-0.0391(0.0097)**	-0.0051(0.0038)	0.0087(0.0022)**	-0.0087(0.003)**	0.0022(0.0029)
1980-85	0.0018(0.0014)	-0.0501(0.0112)**	-0.004(0.0043)	0.0106(0.0017)**	-0.0118(0.0034)**	0.0032(0.004)
1985-90	0.0028(0.0015)	-0.0556(0.0186)*	-0.0026(0.0048)	0.0131(0.0019)**	-0.0111(0.0037)**	0.0069(0.005)
1990-95	0.0045(0.0018)*	-0.0525(0.0235)	0(0.0044)	0.0168(0.0021)**	-0.0008(0.0038)	0.0136(0.0057)*
1995-00	0.0053(0.002)*	-0.0349(0.0272)	0.0043(0.004)	0.0203(0.0021)**	0.0086(0.0036)*	0.017(0.0048)**
2000-05	0.005(0.0021)*	-0.0269(0.0281)	0.0077(0.0041)	0.0233(0.0023)**	0.0154(0.0035)**	0.0197(0.0049)**
2005-10	0.0029(0.0022)	-0.0218(0.0302)	0.0074(0.0049)	0.0255(0.0026)**	0.0186(0.0034)**	0.0184(0.0056)**
Intercept	0.0163(0.0017)**	-0.0071(0.0095)	0.0004(0.002)	0.0059(0.0017)**	-0.0089(0.0036)*	-0.0094(0.0044)*
N	492	72	264	276	468	276
R^2	0.034	0.1645	0.055	0.5557	0.2311	0.1565

Coefficient (standard error) from pooled ordinary least squares regressions controlling for year. Standard errors are robust, clustered by country. A */** next to coefficient indicates significance at the 5/1% level.

the Caribbean and the Middle East and North Africa all have negative intercepts, indicating that their regression lines are starting at higher fertility levels, while East Asia and the West are starting at lower fertility levels.

For v_2, relationships with GDP and women's schooling were consistent with the multivariate models. The correlation between GDP and v_2 was of similar magnitude in the random effects model but the magnitude of the correlation between the proportion of women with any schooling increased substantially in the random effects model. The positive relationship with GDP, indicating that higher levels of GDP are associated with lower fertility at younger ages, is robust, and the negative relationship with women's schooling, indicating that as more women have access to some education there is lower fertility at older ages (earlier stopping) is stronger in this model. Latin America and the Caribbean and the West had similar, negative intercepts, while the other regions had positive intercepts, indicating that the West and Latin America and the Caribbean regression lines begin with lower fertility at older ages than the other regions.

For v_3, only year as included in the country-level portion of the model, with an intercept for each region. While the multivariate model and the stratified models showed a strong relationship between time and v_3, these effects were greatly diminished in the random intercept model. There was substantial variation in the regional intercepts, indicating that regions started at very different places prior to the beginning of this time series.

Table 4.8: Results for Models with Random Intercept for Region

	v_1	v_2	v_3
Life Expectancy	0.0001(0)**		
Logged GDP	0.001(0.0002)**	0.008(0.0011)**	
Women Schooling	0.0059(0.0005)**	-0.0282(0.0037)**	
1950-55			*reference*
1955-60			-0.002(0.002)
1960-65			-0.0033(0.002)
1965-70			-0.0024(0.002)
1970-75	*reference*	*reference*	-0.0027(0.002)
1975-80	0.0006(0.0003)	-0.0012(0.0026)	-0.0026(0.002)
1980-85	0.001(0.0003)**	0.0002(0.0027)	-0.003(0.002)
1985-90	0.0015(0.0004)**	0.0031(0.0027)	-0.0016(0.002)
1990-95	0.0021(0.0004)**	0.0024(0.0027)	0.0035(0.002)
1995-00	0.0028(0.0004)**	0.0056(0.0027)*	0.0084(0.002)**
2000-05	0.0029(0.0004)**	0.0088(0.0027)**	0.0117(0.002)**
2005-10	0.0026(0.0004)**	0.0111(0.0027)**	0.0122(0.002)**
Intercept	0.003(0.0018)	-0.0476(0.0091)**	-0.0042(0.0078)
Random Effects Parameters			
var(Intercept)	0.00001	0.0001	0.0035
var(Residual)	0.00001	0.00041	0.0001

Coefficient (standard error) shown from models with random intercepts for region. for each factor from pooled ordinary least squares regressions controlling for year. A */** next to coefficient indicates significance at the 5/1% level.

Table 4.9: Random Intercepts for each Region for Models for Each Weight. Random intercepts for each region are shown for models in Table 4.8

	v_1	v_2	v_3
SSA	-.0032	.0012	0.0210
East Asia	.0055	.0154	-0.0352
South Asia	-.0005	.0023	0.0024
LAC	-.0031	-.0129	0.0190
West	.0037	-.0123	-0.0069
MENA	-.0024	.0062	-0.0003

4.5 Discussion

Using these newly developed parameters for capturing age-specific fertility of a population, this analysis has interrogated existing theory around fertility decline by investigating how factors previously demonstrated to be related to global fertility decline are associated with these parameters, specifically allowing for examination of how these factors affect the shape of age-specific fertility curves.

Mortality Mortality measures, infant mortality and life expectancy, demonstrated the expected relationship with overall fertility. Namely, higher mortality country-periods also had higher overall fertility. However, no relationship was detected between v_2 or v_3 with mortality, meaning no relationship was found between the shape of the age-specific fertility curve and mortality. This suggests that while mortality levels are related to overall level of fertility, mortality levels do not influence *when* in the reproductive age span women are having children. This suggests that there may not be a cohesive change in behavior at the population level in response to mortality level because, if, for example, low mortality led couples to adopt earlier stopping behavior a relationship between v_2 and mortality would be expected. If the behavior was more complex, and couples were both delaying onset of childbearing and practicing earlier stopping, while a relationship with v_2 may not be detected, there would be a relationship with v_3 as the curve would have to change shape reflecting heavier concentrations of fertility in the middle reproductive ages. The absence of effects on v_2 and v_3 in the presence of strong regional and temporal associations suggest that there may be regional patterning in these relationships. Even for the relationship seen on v_1, the stratified and multilevel models indicated very different relationships across the regions.

Economic Development Operationalizations of economic development often address different aspects of what can be a broad definition. Looking at three measures, the commonly used GDP, the Gini coefficient and HDI, economic development largely behaved as hypothesized. GDP was significantly associated with overall level, as expected, with higher GDP associated with lower fertility. This same pattern was seen for the broader measure of development used, HDI. HDI was also associated with v_2, indicating that higher levels of development were associated with lower levels of early fertility. This finding is the opposite of what was hypothesized, that higher measures of development would be associated with lower later fertility instead. However, the interpretation here is that higher measures of HDI are associated with a delay of the onset of childbearing that outweighs any declines in fertility at later ages. Looking at the Gini coefficient, higher inequality was associated with flatter curves, though related to neither overall level nor to the balance between early and late fertility. This finding is consistent with the hypothesis that higher measures of development, in this case more economically equal societies, would have more peaked fertility curves, with fertility concentrated in fewer reproductive ages. Logged GDP was retained in stratified and multilevel models for v_1 and v_2 where regional variation was found to be substantial. In stratified models, the relationship with overall level only remained detectable for SSA and

South Asia, while the relationship with lower early fertility was only detectable for the West. From multilevel models, the relationship was not consistent across regions.

HIV The complex relationship between HIV and fertility made it impossible to generate directed hypotheses to test, though evidence was found for the general hypothesis that some relationship exists. In the models looking only at HIV, higher HIV prevalence was associated with higher fertility levels and with flatter age-specific curves. Given the geographic patterning of the HIV epidemic and high fertility, both in SSA, this is not unsurprising and these results may reflect solely SSA fertility characteristics, particularly given the restricted population under study in these models. The detection of a relationship here, however, provides evidence that a relationship exists and suggests that further study with more detailed datasets would provide further insight into this relationship. Specifically that there is a detectable relationship between HIV prevalence and the shape of the age-specific fertility curve suggests that further study, particularly with more detailed information from high HIV prevalence populations, may be able to yield insight into this relationship, and from that, insight into the mechanisms underlying that relationship.

Women's Education Often used as a marker for women's empowerment and specifically women's ability to make their own decisions about childbearing, women's education measures were shown to have a strong association with age-specific fertility. As hypothesized all four measures used here were strongly associated with v_1, and higher measures of women's education or empowerment were associated with lower overall level of fertility. Both female labor force participation and women with any schooling were associated with lower fertility at later reproductive ages (negatively associated with v_2), indicating an association with early stopping behaviors. This analysis did not find evidence that increased women's education was associated with lower fertility at early ages, which would have required a positive relationships with v_2. Female literacy rate, female educational attainment and women with any schooling were associated with fertility more concentrated in the middle reproductive ages. The limited data available restricted multivariate, stratified and multilevel modeling to using women with any schooling (which performed consistently with the other indicators) and women with any schooling retained its relationship with overall level and reduced later fertility in multivariate models. However, looking at the stratified and multilevel models, it is clear that this relationship, too, varies substantially by region. The association with lower fertility was detectable for SSA, Latin America and the Caribbean, the West and the Middle East and North Africa in stratified models, though the association with lower fertility at later ages was only detectable for LAC and the West. Multilevel models similarly indicated substantially different relationships between women's education and fertility across regions.

Contraception The CPR measures overall contraceptive use while unmet family planning need seeks to measure the size of the population that would be using contraception if they had access. When tested alone, higher CPR was associated with lower fertility as was lower unmet family planning need, as hypothesized. Additionally, higher unmet family planning need was associated with higher later fertility, which likely reflects the use of contraception for stopping childbearing, particularly in areas with high fertility (which provided most of the data for the unmet family need measure). The limited population for which data was available for these measures greatly restricted the sample used for multivariate models so they were not included in other models.

Urbanization A higher proportion of a population living in urban areas was associated with lower overall fertility, as expected, but no associations were detected related to the age-specific fertility curves. It is likely that country-level analysis is not the best approach to investigating the role of urbanization on age-specific fertility curves given the integral role rural-urban migration patterns are to the mechanisms. Though data coverage was good, proportion urban was not included in multivariate models as once indicators for mortality, development and women's education were added, urbanization no longer was associated with the component weights and the models were better able to explain variation in the component weights without the inclusion of urbanization.

African Exceptionalism First, it is true that SSA age-specific fertility curves are not changing even when fertility declines. Second, while we find that SSA is behaving differently from the West, or East Asia, what we find are clear regional patterns and that this does not make SSA exceptional, but suggests that all regions have different relationships between determinants of decline and fertility and age-specific fertility regimes. These results do not support the idea of African Exceptionalism, but instead provide evidence that relationships seen at the global level are actually the result of strong relationships in some regions masking the lack of a relationship in other regions, most notably these factors perform most consistently for the West and less consistently for other regions. SSA's "exceptionalism" appears to merely be its regional characteristics, and all regions have a regional characteristic.

4.6 Conclusions

Overall, this analysis corroborates predictions made in the literature about how age-specific fertility curves are affected by determinants of fertility decline. Though this evidence is not overwhelming, the results here suggest that relationships may be found to be more robust in more detailed datasets examining fertility with regions, within countries or at sub-national levels, which would allow for further exploration of these mechanisms though would not allow for global comparisons. However, some hypothesized relationships were not born out at all, notably the association between low mortality and stopping behavior. Furthermore, the evidence indicates that these relationships are greatly tied to world region, with different fertility patterns and factors correlated with fertility patterns across regions.

Each region appears to have a distinctive pattern of age-specific fertility, including SSA. Rather than finding evidence of Africa Exceptionalism, however, it is clear that while SSA has a unique age-specific fertility curve, so does every region. While earlier work found similarities between East Asia and the West, for example (for example see Knodel, 1977), examining global patterns over 50 years indicates that there are also stark differences and that, furthermore, other world regions do not conform to the patterns seen as applicable to East Asia and the West. Rather than argue for African Exceptionalism, the regional characteristics demonstrate that it is challenging to tell a cohesive story about global fertility decline because of the substantial nuance evident at the sub-global level. Having used relatively arbitrary geographical region groupings, it is easy to hypothesize that further disaggregation, to sub-regions or country level analysis, or further to sub-national analysis, will reveal even more diversity of patterns. This nuance is similar to that found when disaggregating country-level analysis to compare urban and rural areas (Garenne, 2011; Machiyama, 2010), or women based on level of education (Ezeh et al., 2009; Westoff and Cross, 2006) and further demonstrating that there is not one simple pattern for fertility decline across populations. Or, as Hirschman (1994) puts it, that there are different paths to low fertility.

Temporal trends are strong for overall fertility level but less pronounced and interpretable for either the balance between early and late fertility or for the concentration of fertility in middle reproductive age. This finding calls into question the idea that age-specific fertility curves will change in an established pattern as fertility declines. In stratified models, it is clear that the temporal trend associated with overall level is dominated by the West and nearly absent from other regions. Similarly, the West appears to have a strong temporal trend in the balance of early and late fertility while other regions see little temporal patterning in this parameter. Meanwhile, the relative flatness of the curve seems to have a temporal trend for LAC and to a lesser extent for the West, while again less consistent time effects seen in other regions.

A major obstacle to understanding fertility transition and its causes is the dearth of data. Even when we are able to construct a substantial time series of fertility data we frequently are not able to get data over the same period for key predictors. As a result we are frequently testing theories over time periods that are demographically quite short. In the case of data for countries undergoing demographic transition, almost always the data come from surveys which though allowing for the inclusion of many relevant covariates also means that the time period under study is quite short. In fact, frequently we are forced to analyze simply the period between two surveys. Data availability is a limitation of this study, particularly for covariates of interest. To analyze multivariate models with all the factors of interest the time frame would be constrained to one or two decades at the most and would exclude much variation in fertility level in many countries or regions under analysis. For example, only lowest low fertility for the West and East Asia would be included, and only most recent, replacement level fertility would be included for many countries in LAC or South Asia. To provide a context for SSA fertility requires that higher fertility levels from other regions be included - otherwise SSA will always be an outlier without comparison to similar levels of fertility in other countries and regions.

The lack of global coverage of HIV prevalence makes interpretation of these results suspect, though what these results demonstrate is that there is a detectable effect between HIV and fertility and suggest that further research with other data would likely provide insight into the relationship between HIV and fertility. In particular, in addition to being able to analyze the relationship between overall fertility and HIV prevalence, there may well be an affect on the age-specific fertility curve, providing insight into the mechanism by which HIV is affecting fertility.

Chapter 5

CONCLUSION

This dissertation sought to address some of the challenges to understanding modern fertility regimes and fertility dynamics posed by persistent high fertility in SSA by examining SSA fertility in a global, demographic context. Of particular interest was to ensure a long time frame was considered in all analyses in order to be able to look at trends over decades.

First, using data for a sub-national population in Zambia, I examined male subfecundity. This study showed that men experience age-related declines in fecundity as well as women. Their decline is not as sharp but is still sizable and likely contributes to the overall shape of the age-specific fertility curve, i.e. the apparent and established decline in women's fecundity with age is likely in part reflecting a decline in the fecundity of their partners, too. This research is based on a sub-national population of Zambia because the type of data required - unions and births for men in a non-contracepting population - are rare. However, I compared my data for the women, for whom these data are more commonly collected, to the population of Zambia and found it consistent with those estimates. Furthermore, estimates for women were consistent with those seen for women in other populations. Of note, however, even these estimates are limited to women in developing countries and also constrained by the requirement that there be negligible levels of contraception use in a population, which not only procludes repeating this analysis in many contemporary countries but also makes applying these same methods to other countries in SSA or elsewhere in later years inappropriate. As a result, this analysis of male subfecundity would be difficult to replicate elsewhere given data limitations. However, it seems logical to assume that if measures for women's subfecundity in this population were consistent with that seen in other populations that the male subfecundity estimates would similarly be consistent with other populations as well. In isolating this investigation to the empirical estimates of subfecundity we can extrapolate that while there would likely be some variation across populations, perhaps even quite large variation, we can be safe in interpreting this trend to apply in general to human fertility - that male fecundity, like women's, declines steadily with age. This pattern, seen in an SSA population, would likely be similar to the pattern seen in other populations, given a reasonable amount of variation.

Second, I apply a method for deconstructing age-specific demographic rates to fertility, which allows for describing age-specific fertility curves in reduced, interpretable parameters. Age is an important part of fertility. In addition to the role of age in fecundity, age-patterns of fertility have been theorized to be markers of fertility transition: does the population start childbearing early or late; does the population stop childbearing early or continue until fecundity declines; or are births spaced far apart or close together? All of these behaviors are, in theory, markers of a population's fertility decline and through reducing fertility at certain ages, reduce overall fertility levels. Given the variation in fertility over time and place associated with patterns of fertility decline, one expects to finds patterns in age-specific fertility curves over time and place. Instead, I have found that, using this parameterization of age-specific fertility curves for a global dataset spanning sixty years, patterns of age-specific fertility in a population do not change much over time even during fertility decline, regardless of pace. In fact, the general age-specific fertility curve is consistent over time in many populations. There are consistent patterns in the age-specific fertility curves that deviate from this basic curve and, rather than finding a temporal component, these shapes were associated with certain populations instead. There were substantial regional characteristics to the patterns of age-specific fertility. That being said, SSA's patterning was not any more or less unique than those of other regions. SSA age-specific fertility curves were overwhelmingly traditional in shape, but so were curves in LAC and South and Central Asian countries, and even in some Western countries.

Lastly, using the parameterization of age-specific fertility curves developed in this dissertation I test relationships from the literature used to explain and understand population fertility decline. SSA is different, but so is every other region. Relationships expected from demographic transition theory and empirical work are largely driven by the West in most of the models tested here. Even when looking at the global context, signals from the West were strong enough to come through for many relationships, such as logged GDP being associated with lower fertility at younger ages. However, by and large, what I found was that, at the longer time scale of 60 years, there was limited evidence that these factors were associated with particular patterns of age-specific fertility generally but there was strong evidence of relationships within regions. in some cases. For overall fertility level, higher GDP was associated with lower fertility in SSA and South and Central Asia, while higher proportions of women with any schooling was associated with lower fertility in SSA, LAC, the West and MENA. Higher GDP was associated with lower early fertility in the West while more women with any schooling was associated with lower late fertility in the West. Higher proportions of women with any schooling in LAC was also associated with lower older fertility. Additionally, as data forced me to restrict my time frame, it seemed that some relationships may be stronger in certain eras or on smaller time scales (though the lack of historical data of course keeps one from being able to verify this). There are *real* relationships present in these large, noisy models and better data for sub-populations could likely pull out strong evidence of how these factors are associated with fluctuations in age-specific fertility and thus explore the mechanisms by which these factors influence the total fertility rate. For example, the highly restricted models investigating the relationship between HIV prevalence on the age-specific fertility parameters indicated some relationships were present. Demographic Surveillance Site data is collected in a number of high prevalence areas and would provide detailed information for both fertility and HIV over course of the HIV epidemisc allowing for more detailed examination of this relationship. The illustrative example for Sweden in Chapter 4 showed the nuance that these parameters can capture when working with such detailed data.

In conclusion, fertility in SSA neither follows patterns nor exhibits the same relationships with determinants of fertility as the West even when looking at a long time scale and using processed (smoothed) data. However, neither does any other world region with any consistency. SSA is much like other world regions in that it has regional characteristics, though it shares common characteristics with other regions. For example, the overall curves are generally traditional even through fertility decline, much like what is seen in LAC and South and Central Asia. Relationships seen between overall fertility and life expectancy in SSA were similar to those seen in the West and in MENA, relationships with GDP and women's schooling with overall fertility were similar to those seen in South and Central Asia. In considering longer term population growth, this certainly suggests that fertility decline in SSA, though slow, will likely continue to decline as it has done everywhere else in the world; the secular trend of fertility decline, with very different slopes, is the one clear commonality across regions. Unfortunately, this evidence does not provide insight into the pace of decline. Instead, what this work demonstrates is the importance of age in fertility and its decline and the complexity of the relationship between age and fertility and other factors influencing a population's fertility through time. The available data is too sparse and/or too coarse to model these relationships on the scale and time period desired to truly investigate SSA's fertility patterns within a global context given this complexity. The strength of regional and secular trends, however, point to the importance of modeling these relationships at this scale in order to have an inclusive and comprehensive understanding and theory of fertility decline and its drivers.

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Appendix A

RESULTS FOR TWO APPROACHES TO CONTRACEPTION USE IN ZAMBIA DEMOGRAPHIC AND HEALTH SURVEYS

Predicted probabilities of *subsequent infertility* are presented in Figure A.1, plotted with 95% confidence intervals. While contraception prevalence remained low, the estimates produced by the two approaches are quite close. However, for the 2007 data, which saw the highest contraception prevalence, there was substantial divergence, particularly in later age groups. As expected, with higher levels of contraception use, these estimates diverge. However, even with the substantially lowered estimates of subsequent infertility in the 2007 estimates, there is still evidence of a sizable burden of infertility in the population. These age patterns of increasing infertility with age are similar to those found for other African countries by Larsen (2000) and, like the estimates for other sub-Saharan African countries, are higher at each age group and have a slightly steeper slope than estimates computed for the Hutterites, a natural fertility population in the US (Larsen, 2000).

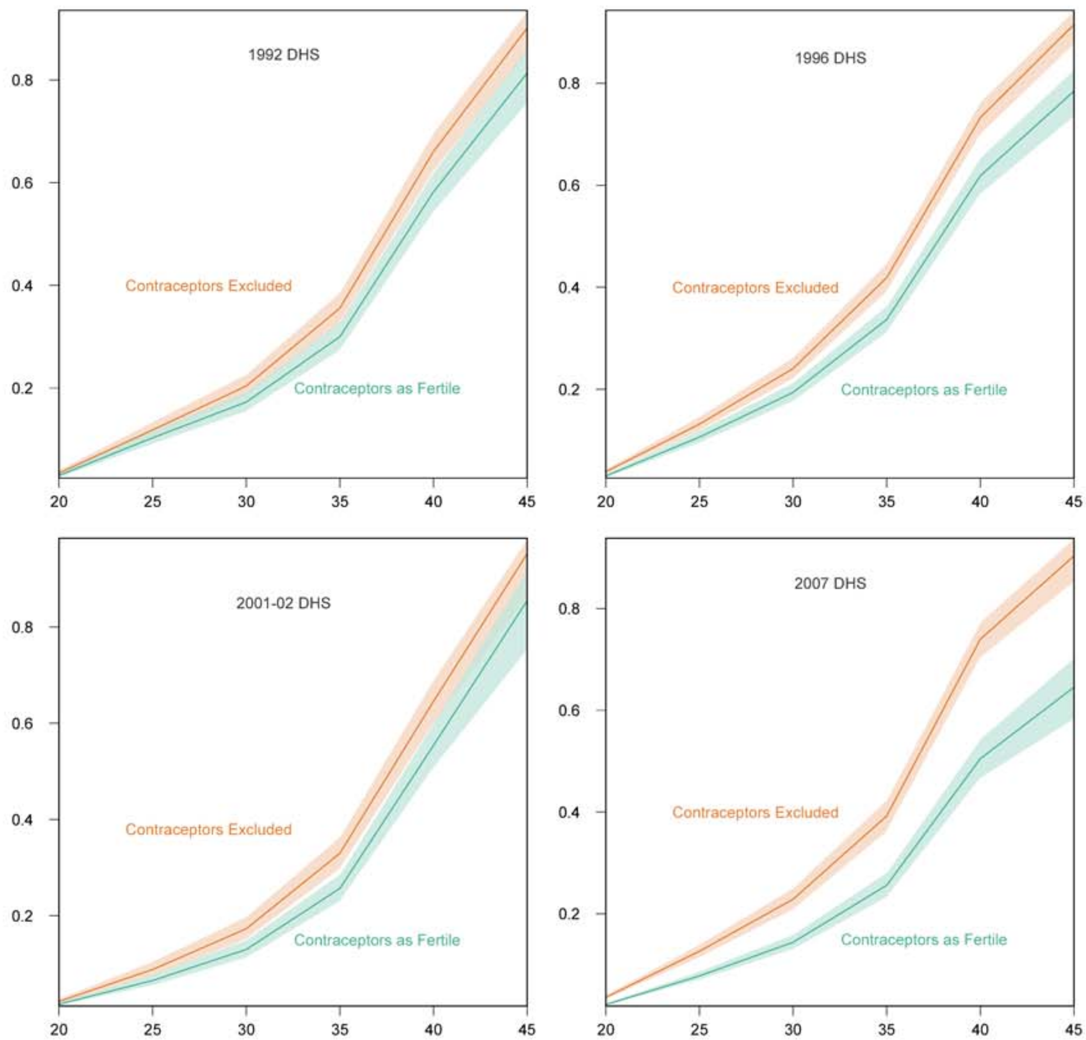

Figure A.1: Predicted probabilities for being *subsequently infertile* by age for both approaches for addressing contraception, by ZDHS dataset.

Appendix B

WORLD REGIONS

Sub-Saharan Africa (SSA): Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Congo, Côte d'Ivoire, Democratic Republic of Congo, Eritrea, Ethiopia, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Somalia, South Africa, South Sudan, Swaziland, Togo, Uganda, United Republic of Tanzania, Zambia, Zimbabwe

East Asia: China, Hong Kong, Democratic People's Republic of Korea, Japan, Mongolia, Republic of Korea

South Asia, Central Asia and Oceania: Afghanistan, Bangladesh, Cambodia, India, Indonesia, Iran, Kazakhstan, Krygyzstan, Laos, Malaysia, Myanmar, Nepal, Pakistan, Papua New Guinea, Philippines, Singapore, Sri Lanka, Tajikistan, Thailand, Turkmenistan, Uzbekistan, Vietnam

Latin America and the Caribbean (LAC): Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Trinidad and Tobago, Uruguay, Venezuela

West: Albania, Australia, Austria, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Lithuania, Netherlands, New Zealand, Norway, Poland, Portugal, Republic of Moldova, Romania, Russia, Serbia, Slovakia, Slovenia, Span, Sweden, Switzerland, TFYR Macedonia, Ukraine, United Kingdom, United States of America

Middle East and North Africa (MENA): Algeria, Armenia, Azerbaijan, Bahrain, Cyprus, Egypt, Georgia, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, State of Palestine, Sudan, Syria, Tunisia, Turkey, United Arab Emirates

Appendix C

COMPOSITE MEASURE OF WOMEN'S EDUCATION

I took the four women's education and empowerment variables and grouped countries that performed similarly across the four variables using model-based clustering (mclust as used in Chapter 3). I obtained 5 clusters. It is important to note that, due to missing across these four variables, the sample is quite small, only 241 country-periods remain: 63 from 1990, 100 from 200 and 78 in 2005. Also of note is that this is not random; most of the missing come from developed nations, so there is minimal representation here of Western countries or countries in East Asia. It's likely that some of these groups found here would be combined if we were able to include more developed countries in this clustering.

Figure C.1 shows the clustering membership across the four variables. The first group, in blue, has high values across all the indicators, with nearly universal literacy, about 40-50% female participation in the labor force, and nearly all women having some schooling, averaging about 10-12 years of schooling.This group is largely comprised of Eastern European countries and some South American countries. The second group, shown in red performs slightly less well across all the indicators and includes countries from Southern Africa, South and Central America, Mexico, Southeastern Asia, and Southern Europe (Greece and Italy) as well as some Eurasian and Eastern European countries. Group three, in green, performs poorly in female education but has more variation in female literacy and in female labor force participation. This group The fourth group, in purple contains several West and North African countries, as well as Bangladesh, India and Iran. The fourth group, in purple, has levels of female education in the middle overall but, like group three sees more variation in female literacy and female labor force participation. This group includes more North African and Middle Eastern countries as well as Guatemala, Indonesia, Nicaragua and Sudan. The fifth group, in orange has high levels of female labor force participation but more variation in women's education and literacy than the other groups. This group is comprised largely of countries from SSA and Southeastern Asia, and includes Haiti.

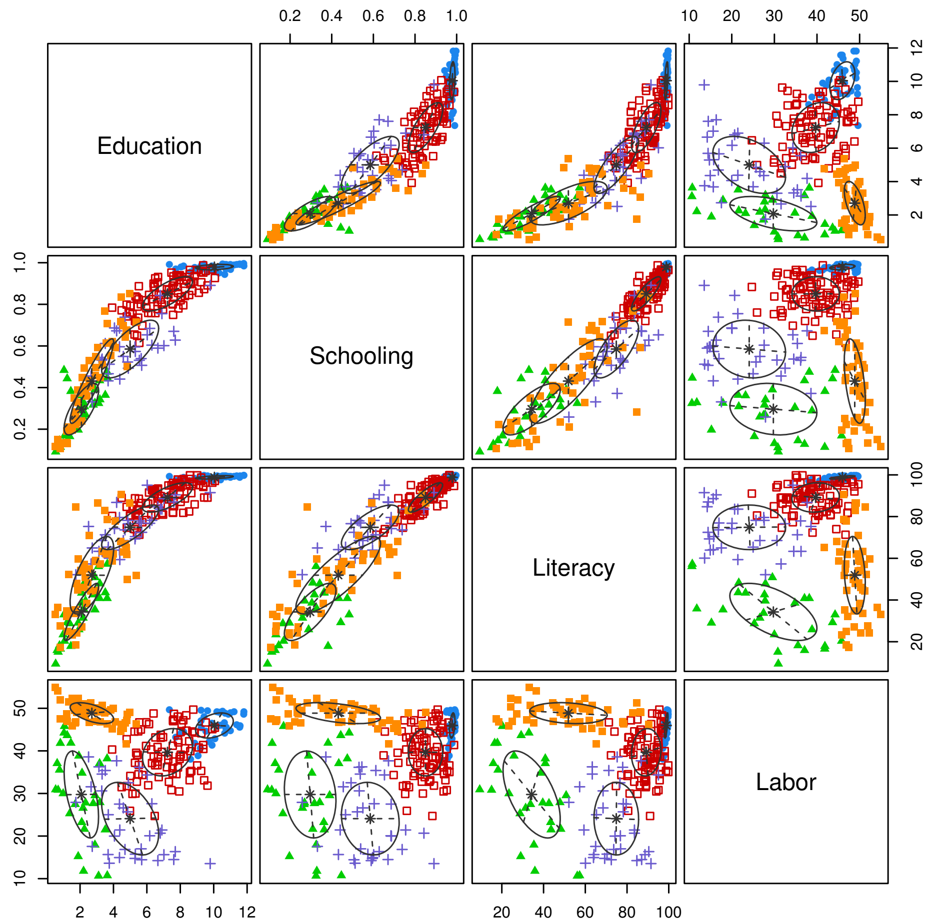

Figure C.1: Clustering across Four Women's Empowerment Indicators: women's educational attainment at age 25 or older; proportion of women with any schooling; female literacy rate; and female labor force participation. Group 1 is in blue, Group 2 is in red, Group 3 is in green, Group 4 is in purple and Group 5 is in orange.