An Estimate of Male Subfecundity in the Gwembe Tonga of Zambia

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A thesis

submitted in partial fulfillment of the

requirements for the degree of

Master of Arts

University of Washington

2012

Committee:

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Program Authorized to Offer Degree:

Sociology

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1. Introduction

A proximate determinant of fertility, subfecundity, is often included but not the primary interest in analysis of population fertility. Demographic of subfecundity, which relies on birth histories, has been strictly limited to women. The Gwembe Tonga Research Project in Zambia, however, has collected five decades of male birth histories, in addition to women's, and using these data, this research seeks to explore subfecundity in a male population by applying methods developed for estimating female subfecundity to these data. With the availability of four subsequent Demographic and Health Surveys for nationally representative samples of women in Zambia, this research also seeks to provide national context for the Gwembe Tonga subfecundity estimates and explore subfecundity trends in Zambia through 2007.

Measuring infertility in any population is difficult. Using the medical definition of failure to conceive after a year of trying overestimates the prevalence of subfecundity as most couples who fail to conceive in one year go on to conceive later. Efforts to estimate population-level burden of infertility from those seeking treatment are subject to substantial selection bias (Menken, 1985). Highly efficacious contraception, increasingly globally available, complicates efforts to observe infertility through population measures as it undermines appropriate inclusion of couples into the set of those at risk of pregnancy. Despite these challenges, infertility is important at both the individual level and the demographic level, deeply affecting personal lives and population dynamics.

Infertility in Africa differs importantly from Western experiences in infertility. Medical studies of global infertility have found marked differences in the cause, with African infertility disproportionately caused by infections (Cates et al, 1985). It has been well documented that infertility has profound social consequences in different and varied populations in sub-Saharan

Africa (Hollos et al, 2009; Hough, 2010; Koster, 2010; Gerrits, 1997) (though social consequences of infertility in the West are also substantial (for example, see Becker, 2000 or Paxson, 2004)). Much of sub-Saharan Africa has limited access to care to mitigate the underlying conditions related to infertility (Hough, 2010; McFalls and McFalls, 1985) and no access to artificial reproductive technologies that are available in the West (Inhorn, 2000), with some exceptions such as South Africa (Dryer et al, 2004) and Zimbabwe (Folkvord et al, 2005). Though important and different, infertility in Africa is not well understood, in part due to the challenges of measurement.

While popular usage relates issues of fertility and sterility to conception, measurement by demographers focuses on live births. This definition most likely fits better with cultural conceptions of infertility in Africa; ethnographic evidence from various African communities has found women consider themselves infertile if they have no surviving children or too few children (Hollos et al, 2009; Hough, 2010; Koster, 2010; Gerrits, 1997). In this paper, sterility refers to the inability to have a live birth, with primary sterility referring to the inability to ever have a live birth and secondary sterility referring to sterility that develops after at least one live birth. Subfecundity refers to the reduced ability to have a live birth.

Fertility rates vary widely across and within countries in sub-Saharan Africa (for example, Bongaarts et al, 1984), and similarly demographic measurement of infertility has shown wide variation across the continent. Larsen (2000) found relatively low rates, rarely exceeding 3%, of primary sterility, across 28 sub-Saharan African countries, but high rates of secondary sterility, measured with Larsen and Menken's subsequently infertile measure. These rates of secondary sterility ranged from less than 10% to 25% for women age 25-44 (Larsen, 2000). Other estimation methods have found similar variation in infertility prevalence across

Africa (Ericksen and Brunette, 1996). Frank (1983) found great variance in rates of primary sterility by country and also by ethnic group in Africa (whether a country was successfully implementing fertility control measures was not considered in this comparison). 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 using anthropological data to assess the proximate determinants of fertility.

Not much data are available to explore the causes of infertility or trends over time, though repeated measurement over time in some populations suggests that some areas have had stable infertility rates while other areas have experienced increases (Larsen, 1994). Frank (1983) and Bongaarts et al (1984) argue that pathological causes, specifically gonorrhea, are responsible for elevated rates of sterility in sub-Saharan Africa and a multinational WHO study investigating worldwide infertility corroborated these findings (Cates et al, 1985). Hough (2010) also found evidence of the role of untreated sexually transmitted infections in infertility in the Gambia. McFalls and McFalls (1984) provide a thorough discussion of the effects of disease on infertility. While they concur that gonorrhea is most likely the primary pathological cause of infertility in sub-Saharan Africa, they demonstrate the potential negative consequences on fecundity of a wide range of diseases and conditions prevalent in Africa, notably including obstetrical complications, schistosomiasis, sleeping sickness, other febrile illnesses that can affect pregnancy, egg production or sperm production (McFalls and McFalls, 1984).

Demographic measurement of infertility in sub-Saharan Africa is important for deepening our understanding of fertility trends and reproductive health in the sub-Saharan context. This widespread variation suggests that it is not possible to generalize about infertility in Africa based on cross-sectional, country or regional measures and motivates investigation of infertility rates in different countries, different ethnic groups, and over time. These sub-national variations are usually much stronger than what is seen at the national level, and national level analysis can hide the true severity of subfecundity at the regional or local level (McFalls and McFalls, 1984). McFalls and McFalls (1984) argue that though there is a genetic component to subfecundity, most likely these differences can be explained through social factors and health-related conditions, such as disease and access to comprehensive obstetrical care. Frank (1983) and McFalls and McFalls (1984) point out that frequently high infertility is found in tandem with high fertility rates and argue that understanding infertility is crucial for understanding population growth in sub-Saharan Africa because if infertility rates decline, fertility rates may increase automatically as contraception practices that were adequate for preventing pregnancy in subfecund couples are inadequate for couples with normal fecundity. Additionally, Frank (1983) and McFalls and McFalls (1984) argue that fears about infertility may encourage earlier marriage and first birth, which, when practiced by the whole population, result in higher numbers of births for couples with normal fecundity, thus linking high rates of subfecundity with high fertility rates through the proximate determinants of fertility.

Population measures of infertility are usually constructed from birth histories of women and thus infertility estimates have been limited to the population of women rather than the general population. However, infertility is a condition experienced by a couple, with causes that could be related to the male partner, female partner or both partners; medical studies (Folkvord et al, 2005) and anthropological studies (Gerrits, 1997; Dryer et al 2004) provide direct evidence of male infertility in multiple locations in Africa. Within a couple, determining whether subfecundity is due to male or female disorders is often difficult due to a general reluctance to take responsibility for it, and generally less is known about male subfecundity prevalence (McFalls and McFalls, 1984). McFalls and McFalls (1984) estimate between 20 and 60% of subfecundity is accounted for in whole or in part by male subfecundity across populations. As sterility, primary or secondary, is potentially related to either the male or female member of the couple, population estimates of male subfecundity would provide insight into population-level subfecundity. In this paper, I seek to demonstrate that male subfecundity can also be measured at the population level through the application of measures based on incomplete birth histories to men.

The objective of this paper is to measure subfecundity among Gwembe Tonga men by using Larsen's and Menken's (1989; 1991) measurement of subfecundity based on incomplete birth histories. Juxtaposed with measurement of subfecundity for the women in the same population, this analysis will seek to describe subfecundity among the entire adult Gwembe Tonga population using demographic methods. Female subfecundity from Demographic and Health Survey (DHS) data from 1992, 1996, 2001-02, and 2007 will also be measured to provide context for the Gwembe Tonga analysis. With these measurements, I hope to both be able to describe the probable limitations of a birth history based measure of male subfecundity as well as demonstrate the need for inclusion of some measurement of male or couple subfecundity when subfecundity is analyzed for a population.

2. Subsequently Infertile Estimates

A variety of methods have been developed to measure sterility and subfecundity in populations. Many have been limited to measuring childlessness, or primary sterility, which is the most straightforward type of infertility to measure. Larsen and Menken (1989) developed a method for measuring the proportion of women who are subsequently infertile after a certain age based on earlier methods developed by Vassen and Henry to measure secondary sterility using complete birth histories. Those categorized as subsequently infertile using this measure are effectively experiencing secondary sterility. Larsen and Menken's (1989) subsequently infertile measure modifies for use with incomplete birth histories a measure developed by Henry for complete birth histories; specifically this modification was intended to allow for measurement of subfecundity with data available through cross-sectional surveys. For this measure, infertility is defined as a woman being observed for a specified time, T, without having a live birth despite being sexually active and not using contraception. This estimate is not actually the number of women sterile at age *a*, but the proportion of women who become sterile between age *a* and age *a*+T at some age a*. This measure is calculated at age *a* only if the woman is continuously observed and married from at least age *a*-5 to age *a*. The proportion of the population that is subsequently infertile is estimated in five year age intervals, spanning from age 20 to 45, as the total number of women indicated to be infertile at age *a*, divided by the total number of women included in the risk set at age *a*. Women are included at the start of their marriage and exit at the termination of their marriage, though they can re-enter if they re-marry (Larsen and Menken, 1989).

The method was compared at different lengths of T and found to perform consistently at 3, 4, 5, 7 or 10 years (Larsen and Menken, 1989). Five years is generally used, 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. In the analyses presented by Larsen and Menken, they found that the five years interval was adequate and argued that in cases of women who had subsequent births outside of the interval, even if they were not subsequently infertile, they were likely subfecund (Larsen and Menken, 1991).

However, exposure to risk of pregnancy is not easy to determine. Even when limiting the analysis to women who are continuously married, some sexually inactive women may be included. Simulation and sensitivity analysis found that the measure was not sensitive to variation in the duration of post-partum abstinence, and the authors argue that terminal abstinence is too rare to be a concern (Larsen and Menken, 1989). However, excluding never married and divorced women from the measurement likely underestimates infertility, particularly as evidence suggests that infecund women are more likely to be divorced than fecund women (Larsen and Menken, 1994).

Contraception further complicates the measurement as women who are practicing contraception could be counted as infertile despite being fecund. Simulations to test sensitivity to contraception use found that contraception used for birth spacing had substantially less impact on infertility estimates compared to contraception used to stop childbearing. In populations with contraception use, sensitivity analysis found that the subsequently infertile measures could be estimated with negligible bias so long as contraception use was limited to very specific conditions in samples of at least 1500 (with stricter conditions for samples of 500-1499). As data with adequate level of detail about contraception use to determine if the population meets these conditions is often unavailable, Larsen suggested in populations with at most 6% of women using highly effective contraception assuming all contracepting women are fertile to provide a conservative estimate of sterility (Larsen, 1994).

3. The Gwembe Tonga, 1957-1955

Zambia, a land locked country in southern Africa, had an estimated mid-year 2011 population of 13,881,336 with a variety of ethnic groups and eight official languages, reflecting a diverse population (*World Factbook*, 2009). The primary focus of this study will be subfecundity among the Gwembe Tonga, who live in southern Zambia, using an anthropological data set collected from 1956-1995 and including data on union formation and fertility (Clark, 2001). Approximately 36% of the population of Zambia lives in urban areas, predominantly the capital Lusaka. Zambia has a population growth rate just over 3%. Life expectancy remains among the lowest in the world (52 years) with maternal mortality and infant mortality rates among the highest at 470 deaths per 100,000 live births and 66.6 deaths per 1,000 live births respectively. An estimated 64% of the population lives in poverty with 85% of the labor force employed in agriculture and 14% of the adult population unemployed. Gini index comparisons rank Zambia as having one of the 25 highest levels of inequality in the world (*World Factbook*, 2009).

Fertility rates in Zambia remain high, with a total fertility rate estimated to be 6.2 in 2007 (CSO et al, 2009). Unlike many of Zambia's southern African neighbors, high fertility rates were not a major political or development concern until the mid-1980s when national population policies were first developed. Even with national policies, there has been limited health infrastructure to commit to family planning (or maternal or infant mortality initiatives) and contraception prevalence rates remained low through the early 1990s (Lucas, 1992). However, contraception use has increased from 15% of women in 1992 to 41% in 2007; 33% of women were using modern methods in 2007, with oral contraception the most popular (11% of women) followed by injectables (8.5%) (CSO et al, 2009). There is relatively little information about sterility in Zambia. One study by Sunil and Pillai (2002) sought to compare sterility in Zambia in 1980 and 1990 and identify relevant social determinants of sterility using Zambia Census data from 1980 and 1990 and the 1996 Zambia Demographic and Health Survey. They used the parity progression ratio, which uses data on children ever born, and found that the proportion of women who were sterile increased from 0.12 in 1980 to 0.15 in 1990. The authors also found evidence of regional variation in sterility, with higher levels observed in Copper Belt Province. The authors estimated that sterility rates in Southern Province, where the Gwembe Tonga live, increased from 0.11 in 1980 to 0.14 in 1990 (Sunil and Pillai, 2002).

The Gwembe Tonga traditionally resided in the valley of the Zambezi River. They are matrilineal, with land and ancestor spirits (shades) passed to descendants of the man who first cleared it as traced through women. However, for inheritance only those living close by are considered, thus keeping the Gwembe Tonga virilocal (Mair, 1974). Gwembe Tonga women marry early (mean age of 16.5) and nearly universally (97% married by age 45). Similarly, fertility rates among the Gwembe Tonga have remained high (with a total fertility rate of 6) through the 1980s (Clark et al, 1995). At the beginning of the period covered by the data (1956-57) in some areas as many as 40% of men were practicing polygyny, most having two wives though some having as many as four. The wives were not ranked; first (or second) wives did not have special privileges (Colson, 1971). Polygyny is still practiced, though has become less common (Clark, 2001). Traditionally, women's families received bridewealth, and damages in the case of pre-marital affairs, which were seen as part of reciprocal exchanges of labor and money in Gwembe Tonga family networks (Colson, 1971).

The period covered by this data set was tumultuous for the Gwembe Tonga and evidence shows that this tumult led to changes in their social organization and behaviors that may impact not only fertility desires and practices but also infertility (Clark et al, 1995). Data collection began, and was initiated because of, the resettlement of the Gwembe Tonga from their river valley for a project to dam the Zambezi River in 1957-58. There is evidence that after an initial period of negative effects from this move, the situation improved for the Gwembe Tonga during the 1960s. However, in the 1970s, the Zambian economy began a long period of decline when the price of oil increased dramatically and the bottom fell out of copper prices. During the War for Zimbabwean Independence, the Gwembe Tonga found themselves in a conflict zone, as the river valley lies on the Zambia-Zimbabwe frontier. The mid-1980s saw severe droughts in the region leading to extended shortages of food and water. Then the late 1980s brought structural adjustment programs mandated by the World Bank, which further negatively impacted Zambia's poor, including the Gwembe Tonga (Clark, 2001).

Over such an eventful period, social practices evolved. There is evidence of marriage practices changing during the period the data covers, and specifically unions becoming less stable. Age at marriage for men appears to have declined and cohabitation became more common without men having to pay either bridewealth or other monetary compensation (called damages) to a woman's family for premarital cohabitation. Prior to resettlement divorce was rare, and post-resettlement divorce was greatly discouraged because of the labor required to clear land for new households. Indeed, widows and unmarried men were pushed into unions to reduce community workload of clearing land for the women-headed households. These unions were often bad matches that dissolved later. By the early 1960s, a practice of "wife stealing" or eloping with married women was becoming common (Colson, 1971). Husbands were frequently absent as well because men left the area for work, and women would take up with other men, which often led to divorce of the absent husband. Sometimes a "pro-husband" would be selected amongst the lineage whose children with the wife would then be considered to belong to the absentee husband, which would preserve the absentee husband's right to inheritance (Mair, 1974).

4. 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 were included in the data set, two villages that were moved away from the Zambezi and two villages that were moved below the dam on the Zambezi. The sample includes all the inhabitants of these villages, and additional individuals enter the sample by being born to someone in the sample, marrying someone in the sample, or having a child with a member of the sample. Individuals leave the sample through death or by moving out of the sample villages and losing contact with all members of the sample (Clark, 2001). The data used for this analysis includes 1872 ever married women age 20 to 79, 1292 ever married men age 20 to 79. Data used included year of birth, year of death, year of union formation, year of union dissolution and year of live birth of each child. These data are ideal for estimating infertility for men because birth histories are available for both the men and women in the sample.

To compare infertility estimates for the Gwembe Tonga with those for the broader context of Zambia, Demographic and Health Survey data from 1992 (ZDHS 1992), 1996 (ZDHS 1996), 2001-02 (ZDHS 2001-02) and 2007 (ZDHS 2007) are used. All surveys were conducted using multi-stage cluster sampling to obtain a population-based sample of households. Sample sizes for male and female respondents are summarized in Table 1 below.

Table 1. Sample Sizes for Zambia DHS Surveys used

Survey Year	Women, age 15-49
1992	7060
1996	7286
2001-02	7658
2007	7146

From ZDHS 1992, ZDHS 1996, ZDHS 2001-02, and ZDHS 2007.

Analysis was restricted to currently married individuals at least 20 years of age in the DHS analysis, since divorce dates were not available to include separated and divorced women over the time they were married. All ever married individuals were included from the Gwembe Tonga data set, with analysis limited to individuals that had been married for at least five consecutive years. The total numbers of individuals included in the analysis are provided in Table 2. The age distributions across all DHS surveys were quite similar, though the Gwembe Tonga dataset had considerably more individuals over age 45; Figure 1 presents the age distributions for the datasets.

Table 2. Population used for analysis: individuals over 20 who were married at least 5 years before the last observation

Gwembe Tonga Men	1021
Gwembe Tonga Women	1405
1992 DHS	3615
1996 DHS	4071
2001-02 DHS	3416
2007 DHS	2264

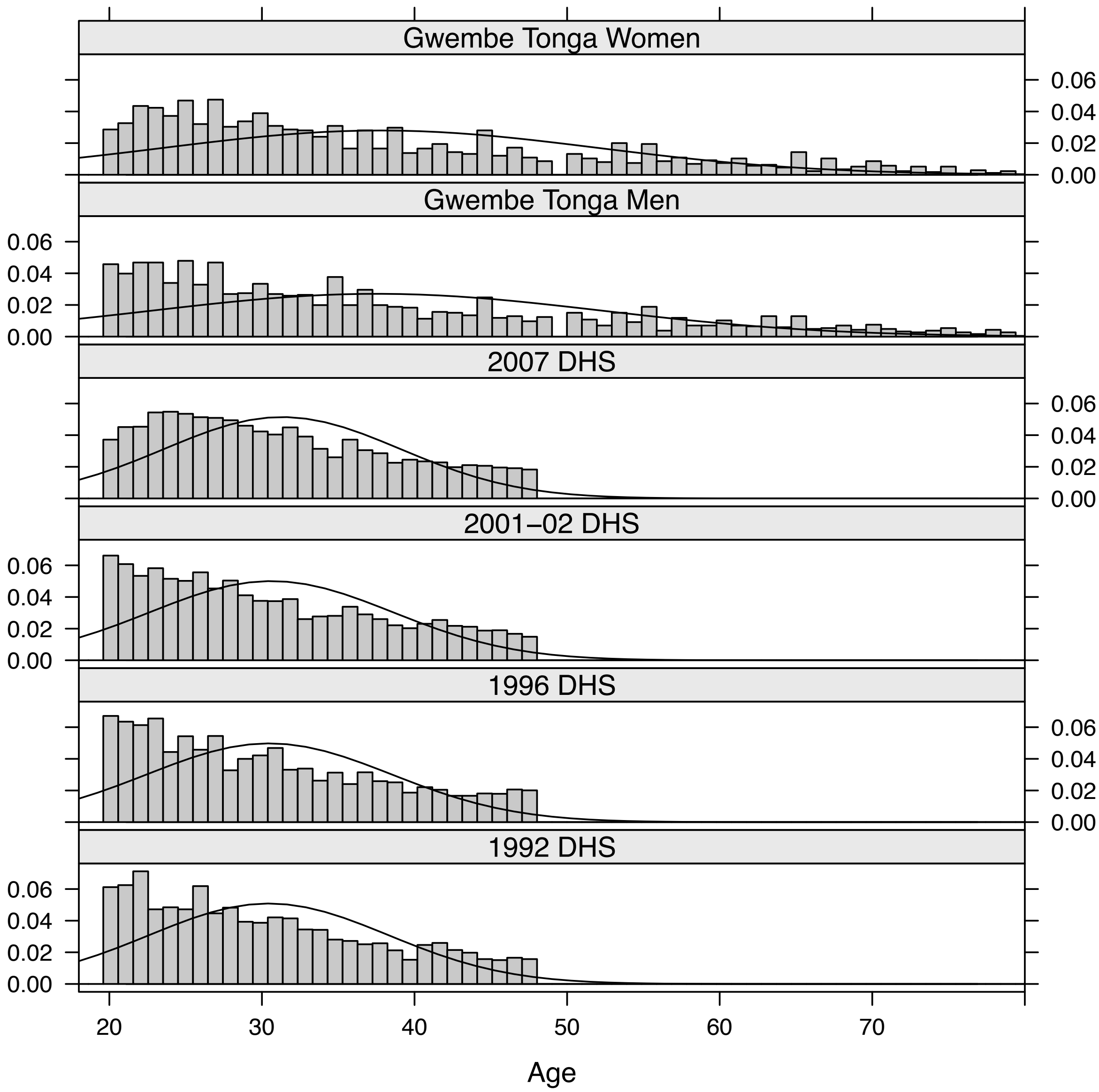

Figure 1: Distribution of age in years for individuals over age 20 included in the subfecundity analysis

5. Methods

The Larsen and Menken subsequently infertile estimate used a life table approach (Larsen and Menken, 1989) and also proportional hazards models using five year age intervals (Larsen and Menken, 1991; Larsen, 1994). For this analysis, their subsequently infertile measure is used in a discrete time event history analysis to analyze secondary sterility. A binary subsequently infertile indicator was computed for each person-year observation. To be included in the analysis and thus have this indicator computed the individual had to be observed and married for the previous five person-years. To be determined subsequently infertile, an individual would have had at least one previous birth and have had no births in their next five person-years of observation. Five years of observation without another child from the age, *a*, at which the indicator is assigned were required to categorize an individual as subsequently infertile at age *a* (note that this indicates that at some age after *a* the individual becomes sterile). Unmarried individuals are excluded from the analysis to restrict the risk set to individuals who can be reasonably assumed to be exposed to sex. For Gwembe Tonga populations, inclusion required continuous marriage over the five previous years (though individuals who separated and remarried were included if there was no year in which they were single in the previous five years). For DHS populations, detailed union data were not available so women were included if their date of first marriage was at least five years before age *a*, and they were married at the time of the survey.

This measure was initially used to calculate the proportion of women who were subsequently infertile, in order to estimate the burden of secondary sterility in the population (Larsen and Menken, 1989). Further application assigned individual level indicators of this measure and used proportional hazards modeling to incorporate covariates into the analysis (Larsen and Menken, 1991; Larsen, 1994). Here, a discrete-time event analysis (Allison, 1984) was performed, using logistic regression to estimate the hazards of being subsequently infertile (or not giving birth again) by age and time period for all populations under study. This approach allows incorporation of covariates and the possibility of controlling for age and time period as well as data source or sex when data sets are pooled. This approach enables direct comparison between male and female subsequent infertility among the Gwembe Tonga. This approach also allows for the pooling of all the DHS data for a very large dataset for exploring the different factors impacting women's infertility in Zambia. To correct for independence between observations for women, robust standard errors were estimated for all models.

The data include women aged 20 years and older. To provide rates for five-year intervals, reproductive ages were grouped and treated as a categorical variable. Age groups only covered reproductive years; the age groups used for women were: (1) 20-24 years; (2) 25-29 years; (3) 30-34 years; (4) 35-39 years; (5) 40-44 years; and (6) 45 years and older. In all models presented below, age group 20-24 years is the reference group. Extended age groups were used for men as their reproductive age extends to older ages; the same five year intervals were used for age groups 1-5 with the addition of (6) 45-49 years; (7) 50-54 years; and (8) 55 years and older. For pooled models women's age groups were used.

The Gwembe Tonga and DHS datasets provided data for several decades and a time period variable was created to test for the relationship between time period and subfecundity; these periods were suggested by Thayer Scudder and the GTRP based on their knowledge of the Gwembe Tonga over these six decades (Thayer Scudder, personal communication). The main justification for each period is related to Zambia's overall political economy as well as to specific impacts on the Gwembe Tonga, and these periods are also reasonable for use with the nationally representative DHS data. Period one covers 1950 to 1963, which covers a brief period before the Kariba dam project was announced and relocation and resettlement. Time period two covers nine years of relative stability and economic growth, from 1964 to 1972. From 1973 to 1981, period three, the Zambian political economy deteriorated dramatically, as Zambia went from a middle income country to one of the five poorest countries in the world. Also during this period the war for Zimbabwe Independence resulted in frequent attacks and landmines in the Gwembe Valley that undermined economic and social services. Period four, 1982 to 1990 with deterioration of health conditions as HIV/AIDS was introduced and deeply affected Zambia. Period five, from 1991 to 1999, saw continued health and HIV/AIDS problems, as well as the continued economic stagnation, which were further compounded by increased variability and uncertainty related to rainfall, including flood and droughts. In the final period, 2000 to 2008, there was improvement in the economy and increased access to care and treatment for HIV in Zambia, and generally a period of improvement; there are no data for period six in the Gwembe Tonga data set used here, though some of this period was captured in the 2001-02 and 2007 DHS surveys.

Marital and fertility practices of the populations under study are described first, in order to demonstrate the applicability of the subsequently infertile measure to these populations and explore differences that may affect the measurement. Of particular note for this infertility measure are the increases in contraception prevalence over time in. Hazards of subsequent infertility are estimated for each population separately using covariates for age and time period. Age was included to obtain hazards by five-year age interval; time period was included to control for variations over time. These estimates respond to the primary objectives of this thesis, to describe male infertility by adapting measures for estimating subsequent infertility and to place Gwembe Tonga infertility estimates in the national context. To further explore the relationship between male and female infertile, estimates are presented based on the pooled Gwembe Tonga data for both sexes.

6. Results

6.1 Marriage Practices

Marriage is nearly universal in Zambia and most individuals in all datasets had been married. Table 3 shows the number of individuals ever married and married at the last observation for all data sources. Age at first marriage is young and remained stable over time in the DHS data sets (near age 18 years, see Table 3). Mean age at first marriage was slightly higher for the Gwembe Tonga women, 20 years; mean age of first marriage was older for men, near 25 years (see Table 4). The marriage age for Gwembe Tonga men was also a bit higher than the mean age of first marriage for men included in the DHS (men were surveyed in 1996, 2001-02 and 2007).

Table 3. Female Marital Practices: married population, number of unions, and mean age at first marriage of women, by data source

	Gwembe Tonga	1992 DHS	1996 DHS	2001-02 DHS	2007 DHS
Women age 20 years and older	2206	4800	5637	5487	5269
Ever married women	1768	4516	5219	5063	4747
Currently married women	1538	4467	4216	4068	3899
Percent of women ever married	80%	94%	93%	92%	90%
Women married more than once (%)	143 (8%)	1186 (26%)	1346 (26%)	1240 (25%)	1009 (21%)
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)

Polygyny is practiced among Gwembe Tonga men though it has been declining during the period under study. Clark (2001) found that both polygyny and the hazard for marrying declined for men over this period under study. In these data approximately 26% (337) of men had more than one wife (data, with comparison to DHS data sets are presented in Table 4). Most polygynous Gwembe Tonga men had two wives (68%, 229), and the vast majority of DHS men with more than one wife had exactly two wives. The maximum number of wives at one time was eight for the Gwembe Tonga, but six for two DHS samples and four for the other. Polyandry is not practiced in Zambia. Divorce or separations are not unknown and some level of union instability was seen in both Gwembe Tonga and DHS data. All four DHS surveys showed approximately 25% of ever married women age 20 years and over had been in more than one union compared to only 8% of the Gwembe Tonga married women age 20 years and over. While DHS data only specified whether women had more than one union, for the Gwembe Tonga data the number of total unions ranged from zero to six (though only one woman reported having six unions). The numbers of individuals with multiple unions are also presented in Table 3 (data for men are presented below in Table 4).

Table 4. Male Marital Practices: married population, number of unions, number of wives and mean age at first marriage

	Gwembe Tonga	1996 DHS	2001-02 DHS	2007 DHS
Men age 20 years and older	1900	1307	1591	4829
Ever married men	1258	1041	1341	3910
Currently married men	1042	954	1235	3589
Percent of men ever married	66%	80%	84%	81%
Men married more than once (%)	1,083 (84%)	349 (34%)	524 (39%)	994 (27%)
Men with more than 1 wife (%)	337 (27%)	93 (10%)	122 (10%)	284 (8%)
Percent of polygynists with exactly 2 wives	68%	94%	84%	91%
Maximum number of wives	8	4	6	4
Mean age at first marriage (SE)	25.6 (0.24)	22.8 (0.13)	22.6 (0.11)	22.9 (0.07)

6.2 Fertility

Fertility measures were also similar across data sources. Age at first birth was similar for all populations of women. Mean age at first birth was approximately 18 years for all DHS data sets and 20 years for the Gwembe Tonga women. The Gwembe Tonga men, however, had their first births much later at 25 years on average (data for men's age at first birth was not available in the DHS male datasets). These measures correspond with the mean age at first marriage. Birth intervals for the women have increased over time, with the 1992 and 1996 DHS samples having similar birth interval lengths to the Gwembe Tonga women (which cover similar time periods) and later DHS samples having slightly longer birth intervals. Gwembe Tonga men had slightly shorter birth intervals than Gwembe Tonga women; no data were available for the birth intervals of men included in the DHS surveys.

Table 5. Births: mean age at first birth and mean birth interval by data source

	Mean age in years at first birth (SE)	**Mean birth interval in years (SE)**	**Mean number of live births (SE)**	**Mean number of living children (SE)**
		Women		
Gwembe Tonga	20.4 (0.07)	2.7 (0.02)	4.1 (0.08)	3.1 (0.06)
1992 DHS	18.1 (0.05)	2.8 (0.97)	4.6 (0.04)	3.8 (0.4)
1996 DHS	18.3 (0.04)	2.8 (1.04)	4.5 (0.04)	3.6 (0.03)
2001-02 DHS	18.3 (0.04)	2.9 (1.01)	4.4 (0.04)	3.7 (0.03)
2007 DHS	18.5 (0.04)	3.0 (1.02)	4.3 (0.04)	3.6 (0.03)
		Men		
Gwembe Tonga	25.0 (0.18)	2.4 (0.02)	4.5 (0.16)	3.3 (0.11)
1996 DHS	N/A		4.8 (0.12)	3.9 (0.10)
2001-02 DHS			5.0 (0.11)	4.1 (0.09)
2007 DHS			4.7 (0.05)	4.0 (0.05)

The number of live births to individuals was similar across all datasets and the distributions are shown in Figure 2 for men and women. The distribution of live births for

Gwembe Tonga men is shown with distributions for men in the 1996, 2001-02 and 2007 DHS surveys. The distributions indicate larger proportions of Gwembe Tonga men and women had no births than in any of the DHS data sets. The Gwembe Tonga men's distribution is flatter without as long a tail as any of the women's data sets, though there are ample individuals with high parity in all of the populations and the Gwembe Tonga men's distribution is similar overall to those from the DHS data sets (excepting the large number of men with no births). The number of individuals with no live births is not a measure of primary sterility, presented below, as the distribution below includes all ever married individuals age 20 years and over in the datasets and includes both individuals married for only a short period of time and those no longer married. The elevated number of Gwembe Tonga men and women with no live births compared to DHS men and women is likely related to the inclusion of all adults in Gwembe Tonga villages and the high rates of labor migration that separates Gwembe Tonga men from their wives for extended periods particularly at the beginning of their marriages (Colson, 1971). Additionally, cross sectional surveys are suspected to exclude women with infertility (Larsen, 2000), which would likely be true for men as well.

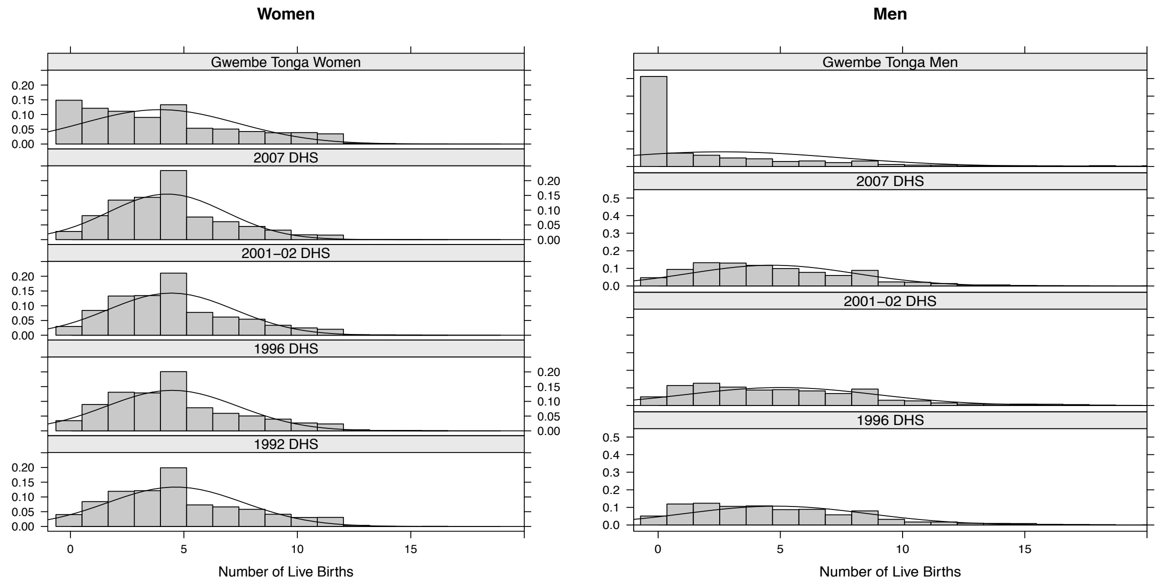

Figure 2. Distribution of live births to individuals by data sources, shown for men and women separately

The distributions of number of living children were also similar across data sets, with similar ranges (though slightly lower maximums than the live births) and distributions. As can be seen from the distribution of live births and distribution of living children, Zambia continues to have high fertility in 2007, with a total fertility rate of 6.2 (CSO et al, 2009). For women at least age 45 at censoring, the mean number of live births was 6.6.

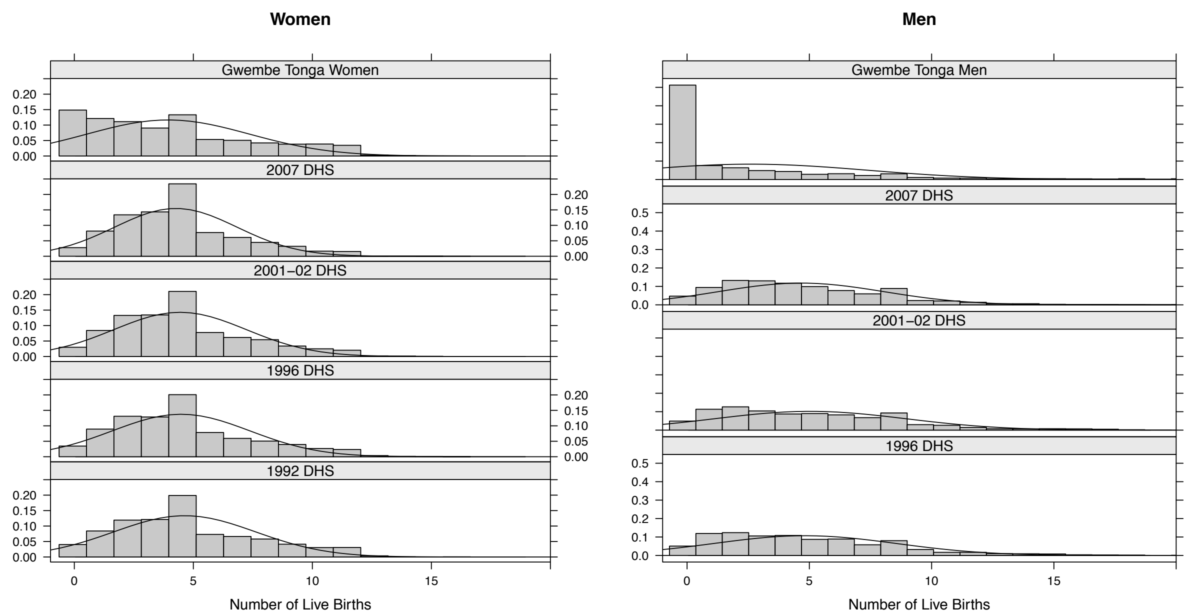

Figure 3. Distribution of number of living children by data source, shown for men and women separately

6.3 Contraception

The Gwembe Tonga data do not include information about contraception use, however contraception use is reported to be negligible among that population through at least 1996. Data from the DHS illustrate a steady increase in contraception use in Zambia starting in the late 1990s through 2007. In 1992, 48% of women had never used contraception and only 16% were using any method at the time of the survey, but by 2007 only 28% had never used any contraception and 33% were using some type of contraception at the time of the survey. Figure 4 below illustrates the steady increase of contraception use among woman and also that use of modern methods in particular has been increasing steadily over this time. This increase in contraception use complicates the application of the Larsen Menken method for estimating secondary sterility; women who are contracepting cannot be easily categorized as fertile or sterile and decisions about how to categorize them risk overestimation or underestimation of the proportion of women with subsequent infertility. Use of efficacious contraception creates a problem because if contracepting women are excluded from the measurement, a substantial proportion of young women are eliminated from the risk set entirely.

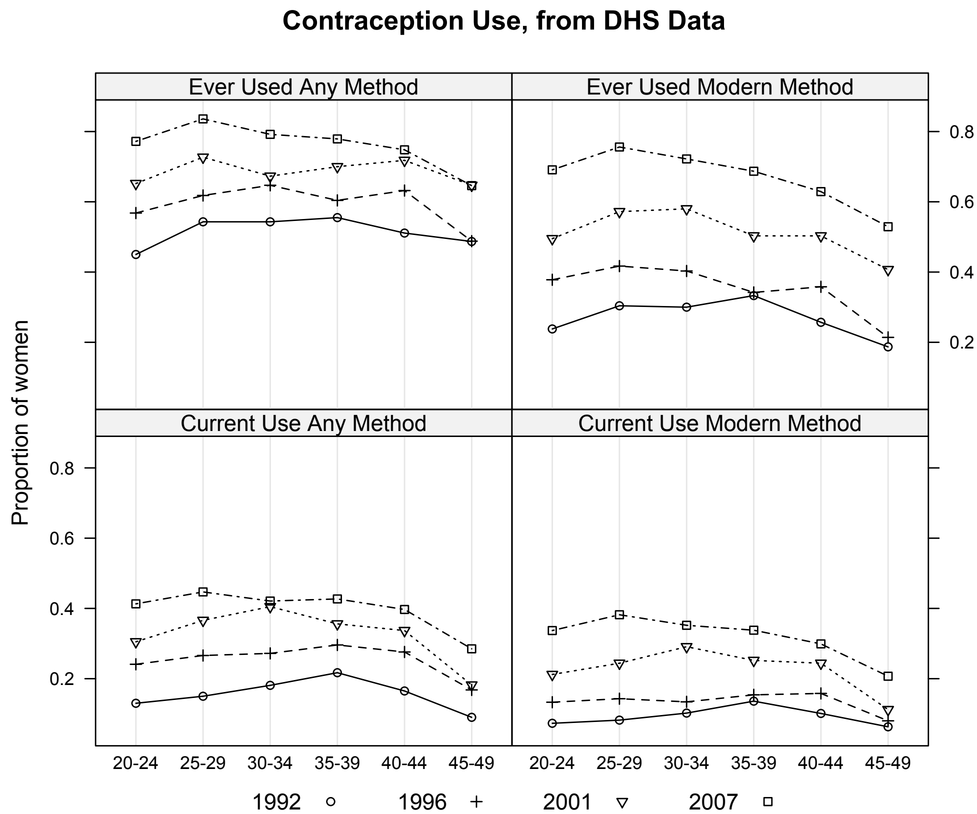

Figure 4. Contraception use over time using DHS data from 1992, 1996, 2001-02 and 2007

Larsen (1994) used sensitivity analysis to determine guidelines for use of the subsequent infertility measure in populations using contraception. To determine if criteria are met data are needed on the proportion contracepting, when contraception use began, the method used, the woman's parity at initiation, and average contraception efficacy (Larsen, 1994). Unfortunately, this level of detail about initiation and consistent duration is not available in the DHS surveys though calculations of the proportion contracepting indicate that sufficient women in Zambia are using modern contraception for it to create a problem for the subsequently infertile estimator. To accommodate contraception use, I present two estimates for each DHS data source. First, I present the estimates for all women who have never used a modern method. This includes women who have used traditional or folkloric methods[1], which I choose to include in the analysis because these forms of contraception would be available and in use in populations with natural fertility, for which these subfecundity measures were originally developed. Additionally, folkloric and traditional methods would not meet Larsen's (1994) specification of "highly effective", which required at minimum an 0.8 efficacy rate. Second, following the approach used by Larsen (1994), I have calculated the estimates in the case where all modern contraception users are considered fertile. This estimate provides the most conservative estimate of secondary sterility, since it is likely that some contraception users are actually infertile without being aware of it. Both estimates are presented below.

6.4 Primary Sterility

The proportion childless among women who entered their first union at least seven years before censoring was used to estimate primary sterility (Larsen, 2000). Since DHS data did not provide adequately detailed marital history, this same measure was used for the Gwembe Tonga data (men and women) despite having person-year detail about their marital status. Childless estimates are presented below for all datasets in Table 6. Childlessness was higher in the Gwembe Tonga datasets with approximately 8% of women and 17% of men being childless after at least seven years of marriage, compared to estimates for the women in the DHS data ranging from 2.4 to 2.7%. These DHS estimates are similar to Larsen's (2000) estimate of childlessness in Zambia using the 1992 DHS. The higher rate for Gwembe Tonga women may be partially explained by the general finding that women with reduced fecundability are sometimes omitted

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[1] Models were initially run three ways, with those using any contraception excluded; only those using modern contraception excluded; and all modern contraception users considered fertile. Estimates did not change greatly between excluding all and excluding only modern contraception users (results not shown), so I decided to retain the folkloric and traditional contraception users as it was likely that those forms of contraception were in use in the Gwembe Tonga population (as they would be in any natural fertility population).

from household surveys or falsely report having children (Larsen, 2000). For the DHS, the lack of adequate detail about marital unions meant that analysis was restricted to only those currently married to meet the assumption of exposure to sex. Union dissolution has often been found to be correlated with infertility including in this population (Clark, 2001) as well as other African populations (Feldman-Savelsberg, 1994; Hollos et al, 2000; Inhorn, 2000; Fortes, 1978) and exclusion of divorced women may cause DHS estimates to understate the level of primary sterility. Additionally, contraception use in DHS datasets was too high for robust estimation of the childless indicator based on the guidance Larsen (1994) derived from sensitivity tests of infertility measures on simulations of survey data for African populations. Larsen (1994) suggests that robust estimates require a sample size of 2500 with no more than 20% of women using highly efficacious contraception for up to three years during the first birth interval. While data about the timing of modern contraception use is limited in the DHS surveys, in both 2001-02 and 2007 use of a modern method is above 20% for most reproductive ages.

Table 6. Childless Estimate: proportion of individuals married at least 7 years without a live birth

Gwembe Tonga, Men	17.10%
Gwembe Tonga, Women	8.10%
1992 DHS, Women	2.41%
1996 DHS, Women	2.73%
2001-02 DHS, Women	2.74%
2007 DHS, Women	2.53%

6.6 Secondary Sterility using the Subsequently Infertile Estimator

Logistic regression was used to estimate the probability of being subsequently infertile, which will just be referred to as infertile for this paper, for all datasets separately with age and time period used as covariates. For the Gwembe Tonga women, a model including interaction terms provided the best fit, see the heuristic formulation of the model below.

$$\ln\left(\frac{p_i}{1-p_i}\right) \sim \beta_0 + \beta_1 \cdot age24-29 + \ldots + \beta_4 \cdot age40^+ + \beta_5 \cdot 1964-1972 + \ldots + \beta_8 \cdot 1990-1999 + \beta_9 \cdot age25-29 \cdot 1964-1972 + \ldots + \beta_{24} 40^+ \cdot 1990-1999$$

Odds ratios with standard errors are presented in Table 7 for the Gwembe Tonga women. The probability of being infertile increases dramatically with age, as expected. The first time period, 1950-1963, is the reference period for this model, and the risk of being infertile is higher for all later periods. The risk is the highest in the last period included here, 1990-1999. To include the interaction terms, it was necessary to combine the last two age categories so that the final age category was all women age 40 years and over. The interaction terms were largely non-significant and small, but their inclusion improved overall model fit.

Table 7. **Odds Ratios** for being infertile, with standard errors, from logistic regression with **Gwembe Tonga data for women**

Age		
20-24	Reference	
25-29	5.55*	(3.16)
30-34	9.78*	(6.19)
35-39	47.03*	(26.64)
40+	72.64*	(47.06)
Time Period		
1950-1963	Reference	
1964-1972	3.07*	(1.77)
1973-1981	2.85	(1.66)
1982-1990	5.85*	(3.07)
1991-1999	28.87*	(14.60)
Interaction: Age & Time Period		
Age 25-29 & 1964-1972	0.63	(0.45)
Age 25-29 & 1973-1981	0.79	(0.51)
Age 25-29 & 1982-1990	0.7	(0.42)
Age 25-29 & 1991-1999	0.6	(0.35)
Age 30-34 & 1964-1972	0.53	(0.42)
Age 30-34 & 1973-1981	0.71	(0.52)
Age 30-34 & 1982-1990	0.71	(0.47)
Age 30-34 & 1991-1999	0.51	(0.33)
Age 35-39 & 1964-1972	0.4	(0.26)
Age 35-39 & 1973-1981	0.37	(0.26)
Age 35-39 & 1982-1990	0.32	(0.19)
Age 35-39 & 1991-1999	0.15*	(0.09)
Age 40+ & 1964-1972	1.78	(1.28)
Age 40+ & 1973-1981	2.52	(1.85)
Age 40+ & 1982-1990	1.21	(0.83)
Age 40+ & 1991-1999	0.49	(0.33)
Intercept	0.01*	(0.004)
Pseudo R^2	0.3294	
Observations	20069	

Cases	1405

* p<0.05

Predicted probabilities obtained for this model by age and by period are presented in Table 8. There is a steady increase with age, approaching a probability of 0.8 for being infertile at the highest ages. The predicted probabilities were lowest for the earliest time period and substantially higher (0.56) for the period of 1990-1999, while the probabilities were stable, around 0.3, for all other time periods. Most person-years were in the final age group (for all models, not just the Gwembe Tonga), and many of the changes to family structure and union formation were compounding throughout the decades and most likely most evident and entrenched in this last period of data.

Table 8. Predicted Probabilities of being infertile, with standard errors, for **Gwembe Tonga Women**

Predicted Probabilities by Age		
20-24	0.07	(0.01)
25-29	0.18	(0.02)
30-34	0.24	(0.03)
35-39	0.39	(0.04)
40+	0.79	(0.03)
Predicted Probabilities by Time Period		
1950-1963	0.14	(0.04)
1964-1972	0.31	(0.03)
1973-1981	0.36	(0.02)
1982-1990	0.39	(0.02)
1991-1999	0.56	(0.02)

The odds ratios estimated for the both contraception scenarios considered are presented in Table 9 for each DHS data set. DHS models that considered all contracepting women fertile (the second model presented for each DHS data set) represent a minimum level of infertility in the population as all contracepting women are included as fertile though presumably a non-negligible proportion of contracepting women may be infertile. The first scenario, where all modern contraception users are excluded entirely from the risk set, shows the risk of being infertile only for women who were not using contraception at the time of the survey. Consistently, the pseudo-R^2 s were smaller for models that treated all women using contraception were fertile than models that excluded contraception users. The models used for 1992, 1996, and 2001-02 datasets included terms for age group and time period, including terms for the time periods represented in the data.

The odds ratio of being infertile increased with age in all models. The relationship between the odds of being infertile and time period was not consistent across models, though was substantially higher for the last time period (1991-1999) for the 1992, 1996 and 2001-02 datasets. For the 2007 data, over 50% of observations occurred in the last time period and the sparseness of observations across the age groups and other time periods resulted in identifiability problems. For that dataset, only the term for the last time period, 2000-2007 was included.

$$\ln\left(\frac{p_i}{1-p_i}\right) \sim \beta_0 + \beta_1 \cdot age24-29 + \ldots + \beta_5 \cdot age45^+ + \beta_6 \cdot 1982-1990 + \ldots + \beta_9 \cdot 2000-2007$$

The same pattern of steady and steep increase in the odds of being subsequently infertile with age was present. The odds of being infertile were two-fold higher for the time period 2000-2007.

Table 9. Odds Ratios with standard errors for being infertile obtained from logistic regression by **DHS data source**, with one scenario excluding all contraceptors and a second scenario where all contraceptors are considered fertile.

	1992 DHS, Contraceptors Excluded		**1992 DHS, Contraceptors as Fertile**		**1996 DHS, Contraceptors Excluded**		**1996 DHS, Contraceptors as Fertile**	
Age								
20-24	Reference		Reference		Reference		Reference	
25-29	3.48*	(0.25)	1.91*	(0.10)	3.50*	(0.21)	2.12*	(0.10)
30-34	6.15*	(0.57)	2.77*	(0.21)	6.76*	(0.51)	3.36*	(0.22)
35-39	11.85*	(1.24)	4.72*	(0.43)	13.87*	(1.19)	5.94*	(0.47)
40-44	37.42*	(4.60)	13.43*	(1.45)	43.44*	(4.75)	15.5*	(1.55)
45+	144.4*	(37.07)	36.54*	(7.24)	142.3*	(32.93)	30.6*	(4.83)
Time Period								
1964-1972	Reference		Reference		Reference		Reference	
1973-1981	1.62	(0.45)	1.52*	(0.30)	8.08*	(5.40)	1.37	(0.43)
1982-1990	3.59*	(1.14)	3.23*	(0.78)	16.82*	(11.91)	2.43*	(0.87)
1991-1999	6.38*	(2.07)	4.62*	(1.15)	40.67*	(29.00)	4.64*	(1.70)
Intercept	0.01*	(0.00)	0.03*	(0.01)	0.002*	(0.00)	0.03*	(0.01)
Pseudo R2	0.22		0.13		0.26		0.16	
Observations	35876		41628		39169		47631	
Cases	3041		3615		3228		4070	

	2001-02 DHS, Contraceptors Excluded		**2001-02 DHS, Contraceptors as Fertile**		**2007 DHS, Contraceptors Excluded**		**2007 DHS, Contraceptors as Fertile**	
Age								
	Reference		Reference		Reference		Reference	
25-29	3.5*	(0.23)	3.4*	(0.23)	3.7*	(0.28)	3.7*	(0.29)
30-34	6.1*	(0.52)	5.8*	(0.51)	7.4*	(0.65)	7.1*	(0.65)
35-39	12.4*	(1.22)	11.2*	(1.14)	14.9*	(1.50)	13.8*	(1.4)
40-44	41.9*	(5.00)	31.9*	(3.74)	53.7*	(6.96)	36.9*	(4.6)
45+	140.2*	37.4*	71.2*	(13.3)	172.0*	(45.56)	65.2*	(11.1)
Time Period								
1964-1972	No observations		No observations		No observations		No observations	
1973-1981	Reference		Reference		Reference		Reference	

1982-1990	1.7*	(0.46)	1.6*	(0.43)				
1991-1999	2.9*	(0.90)	2.5*	(0.77)				
2000-2007	7.0*	(2.22)	4.03*	(1.29)	2.1*	(0.19)	1.6*	(0.14)
Intercept	0.01*	(0.004)	0.01*	(0.003)	0.03*	(0.002)	0.02*	(0.002)
Pseudo R2	0.24		44099		0.24		0.18	
Observations	33212		3744		28576		43040	
Cases	2776		0.19		2318		3636	

* p<0.05

Predicted probabilities of subsequent infertility for five years age intervals are presented in Table 10 compared to Gwembe Tonga women's predicted probabilities and graphed with 95% confidence intervals in Figure 5. 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).

Table 10. Predicted probabilities (with standard errors) of being infertile estimated using logistic regression for DHS and Gwembe Tonga Women data. Results for DHS models treating all contraceptors as fertile are shown here.

Age	**Gwembe Tonga**		**1992 DHS**		**1996 DHS**		**2001-02 DHS**		**2007 DHS**	
20-24	0.07	(0.01)	0.03	(0.00)	0.03	(0.00)	0.04	(0.00)	0.02	(0.00)
25-29	0.18	(0.02)	0.10	(0.01)	0.11	(0.01)	0.12	(0.01)	0.08	(0.01)
30-34	0.24	(0.03)	0.17	(0.01)	0.19	(0.01)	0.21	(0.01)	0.14	(0.01)
35-39	0.39	(0.04)	0.30	(0.01)	0.34	(0.01)	0.37	(0.01)	0.26	(0.01)
40+ / 40-44	0.79	(0.03)	0.58	(0.02)	0.62	(0.02)	0.69	(0.02)	0.50	(0.02)
45+			0.81	(0.02)	0.78	(0.02)	0.92	(0.03)	0.65	(0.03)

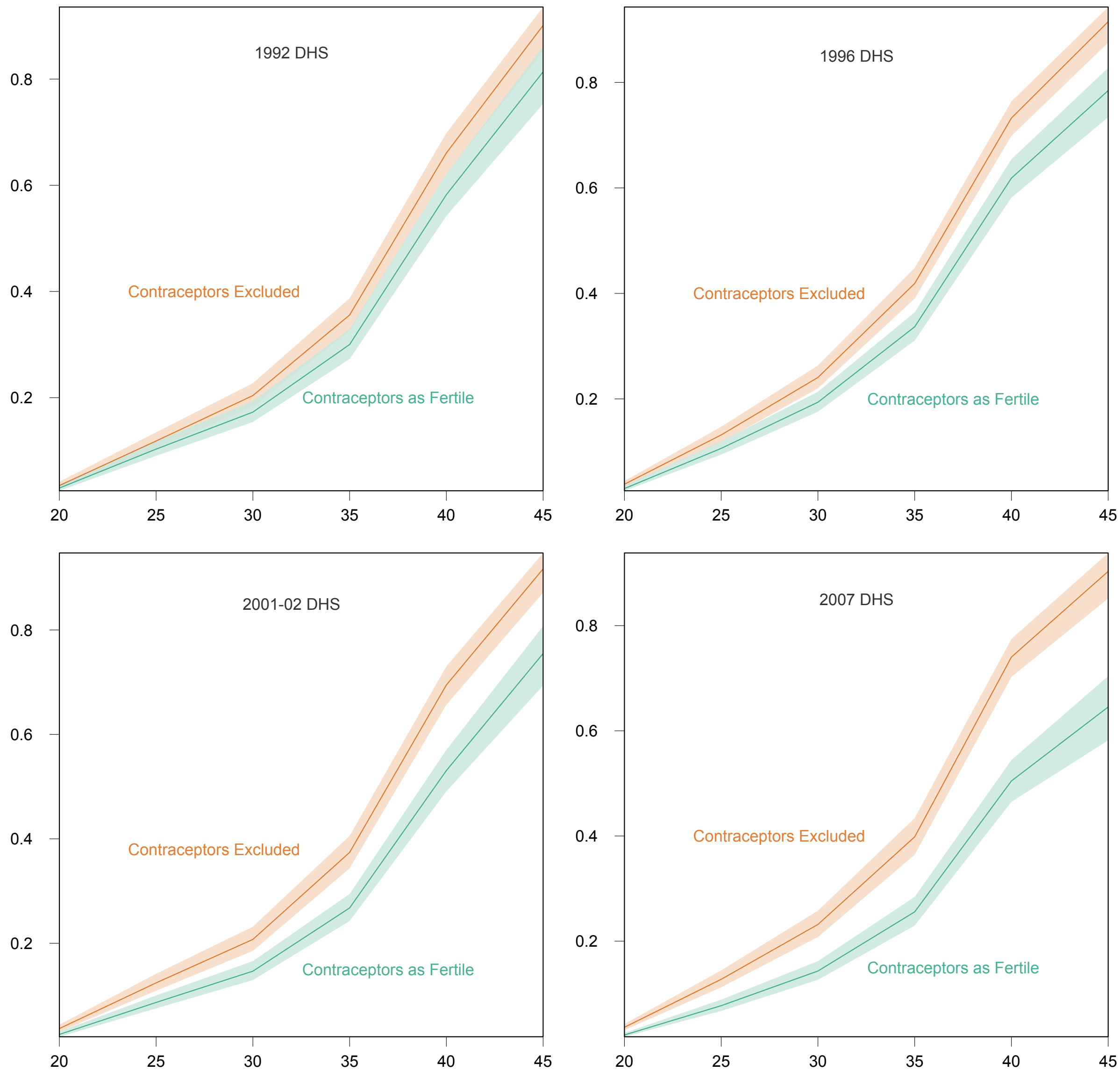

Figure 5. Predicted probabilities for being infertile by age for both approaches for addressing contraception, by DHS data set

Odds ratios for men are presented in Table 11 and were fit using for the model below.

$$\ln\left(\frac{p_i}{1-p_i}\right) \sim \beta_0 + \beta_1 \cdot age24-29 + \ldots + \beta_7 \cdot age55^{+} + \beta_8 \cdot 1964-1972 + \ldots + \beta_{12} \cdot 1990-1999$$

Like women, men's odds of being infertile increased steadily with age. For men odds ratios also increased with time, so that while, like women, they had the highest odds of being sterile in the latest time period, this increase was consistent over all time periods. All coefficients for time period were statistically significant for men, as they were for the Gwembe Tonga and DHS women.

Table 11. Odds Ratios with Standard Error for being infertile obtained from logistic regression for **Gwembe Tonga Men**

Age		
20-24	Reference	
25-29	10.73*	(2.37)
30-34	22.83*	(5.45)
35-39	40.78*	(10.00)
40-44	64.51*	(16.19)
45-49	106.43*	(27.23)
50-54	158.39*	(42.84)
55+	338.50*	(96.66)
Time Period		
1950-1963	Reference	
1964-1972	2.07*	(0.56)
1973-1981	3.24*	(0.99)
1982-1990	5.59*	(1.74)
1991-1999	18.52*	(5.76)
Intercept	0.002*	(0.00)
Pseudo R2	0.29	
Observations	16141	
Cases	1021	

*p<0.05

Predicted probabilities for being infertile by age and by period for Gwembe Tonga men and women are displayed in Table 12. All increase with age, though men begin at a much lower level than any of the populations of women and do not increase as sharply with age. The men see a steady increase with each time period while the predicted probabilities for women are virtually stable from 1964 to 1990, though men have a lower predicted probability than the women at every time period.

Table 12. Predicted Probabilities of being infertile, with standard errors, for **Gwembe Tonga Women and Men** by Age and by Time Period

	Women		Men	
Predicted Probabilities by Age				
20-24	0.07	(0.01)	0.01	(0.00)
25-29	0.18	(0.02)	0.10	(0.01)
30-34	0.24	(0.03)	0.18	(0.02)
35-39	0.39	(0.04)	0.26	(0.02)
40+ / 40-44	0.79	(0.03)	0.34	(0.03)
45-49			0.45	(0.03)
50-54			0.54	(0.04)
55+			0.70	(0.04)
Predicted Probabilities by Time Period				
1950-1963	0.14	(0.04)	0.07	(0.02)
1964-1972	0.31	(0.03)	0.14	(0.02)
1973-1981	0.36	(0.02)	0.19	(0.02)
1982-1990	0.39	(0.02)	0.25	(0.02)
1991-1999	0.56	(0.02)	0.41	(0.02)

Figure 6 shows predicted probabilities for all models graphed with 95% confidence intervals. The Gwembe Tonga women predicted probabilities are notably higher than the DHS sets. At the youngest ages confidence intervals for all DHS datasets overlap and also overlap with the predicted probabilities for the Gwembe Tonga men. At older ages the 2007 probabilities separate from the steeper increases of the other datasets for women, indicating the suppressing effect of higher contraception prevalence on the estimates of subsequent infertility.

Figure 6. Predicted probabilities of subsequent infertility by age estimated by logistic regression for all data sets. Estimates for me extend to later ages while women's estimates stop at age 45 years, which is standard. Gwembe Tonga women estimates stop at 40 years, which includes all women over age 40; this was done to improve model fit for inclusion of interaction terms between age and time period.

Data for Gwembe Tonga men and women were analyzed together to estimate the effect of sex and interactions between sex and time and sex and age to further explore the relationship between sex and infertility. Interactions between time period and sex and time period and age group were not significant, so the final model included terms for age group, time period, sex and an interaction term between sex and age group, as shown below in a heuristic formulation of the model.

$$\ln(\frac{p_i}{1-p_i}) \sim \beta_0 + \beta_1 \cdot age24-29 + \ldots + \beta_5 \cdot age45^+ + \beta_6 \cdot 1964- 1972 + \ldots + \beta_9 \cdot 1990-1999 + \beta_{10} \cdot Female + \beta_{11} \cdot age25-29 \cdot Female + \ldots + \beta_{15} \cdot age45^+ \cdot Female$$

Odds ratios are presented in Table 13. Being a woman increased the odds of being infertile by more than six times, indicating that by this measure infertility is far more prevalent among Gwembe Tonga women than men. In the pooled data the important role of age in the hazard of infertility remains evident as the odds of subsequent infertility at age 25 to 29 years is ten-fold higher than at age 20 to 24 years. The odds increased with time period as well, seeing modest elevated odds through the 1980s compared with the period between 1950 and 1963 and then the odds of being infertile in the final period being more than 14 times greater than in the reference years. The interaction effects between age and being female were not large and for all categories except women age 45 and over, for which the odds ratios are exceptionally large indicating the largest levels of infertility at the oldest age groups in the latest periods. As can be seen with the age-specific predicted probabilities, at this point, women's probabilities of being infertile approach one in this last age category (at least in for Gwembe Tonga women) while even at the oldest age category for men calculated, the probability is still below 0.7.

Table 13. Odd ratios with standard errors for being infertile obtained from logistic regression for **Gwembe Tonga Men and Women** pooled together

Age		
20-24	Reference	
25-29	10.73*	2.37
30-34	22.65*	5.39
35-39	40.05*	9.83
40-44	63.12*	15.85
45+	154.29*	38.88
Time Period		
1950-1963	Reference	
1964-1972	2.06*	0.33
1973-1981	2.57*	0.47
1982-1990	4.20*	0.77
1991-1999	14.50*	2.63
Sex		
Female	6.45*	1.58
Interaction Sex and Age		
Female, Age 25-29	0.33*	0.08
Female, Age 30-34	0.25*	0.06
Female, Age 35-39	0.31*	0.08
Female, Age 40-44	0.8	0.23
Female, Age 45+	2.26*	0.74
Intercept	0.002*	0.00
Pseudo R^2	0.22	
Observations	34555	
Cases	2450	

* $p<0.05$

Data for women from the four DHS surveys were also pooled and analyzed together with explanatory variables included for the data source. Time period and age group categories were collapsed to accommodate the uneven distribution of observations over age groups and time periods, so that 1964-1972 and 1973-1981 formed one time period and the oldest age groups were combined into a 40 years and over category. With these adjustments, a model that included interaction terms for age group and time period was fit (a heuristic expression of the model is shown below for clarity), though the interaction between the oldest age group and 2000-2007 was omitted due to persistent collinearity problems.

$$\ln\left(\frac{p_i}{1-p_i}\right) \sim \beta_0 + \beta_1 \cdot age24-29 + \ldots + \beta_4 \cdot age40^{+} + \beta_5 \cdot 1982-1990 + \ldots + \beta_7 \cdot 2000-2007 + \beta_8 \cdot age25-29 \cdot 1982-1990 + \ldots + \beta_{18} 40^{+} \cdot 1990-1999$$

For this model, the steady and substantial increase in subsequent infertility with age remained evident. For the model where all contraception users were considered fertile, there was a steady increase in the odds of being infertile with time period. The significant and small interaction terms functioned to counteract this increase at younger ages, with the only interaction terms with odds ratios above one being for the interaction between time period and being age 40 years and over.

Table 14. **Odds ratios** with standard errors estimated with logistic regression using all **DHS data pooled** together

	Contraceptors Excluded		**Contraceptors as Fertile**	
Age				
20-24	Reference		Reference	
25-29	6.3*	(0.85)	6.4*	(0.85)
30-34	12.7*	(2.06)	13.3*	(2.16)
35-39	32.8*	(7.48)	34.2*	(7.81)
40+	35.3*	(3.39)	21.0*	(1.84)
Time Period				
1964-1981	Reference		Reference	
1982-1990	2.8*	(0.42)	2.6*	(0.39)
1990-1999	0.8*	(5.20)	4.0*	(0.60)
2000-2007	9.2*	(1.41)	6.0*	(0.92)
Interaction: Age & Time Period				
25-29 & 1982-1990	0.6*	(0.10)	0.6*	(0.10)
25-29 & 1991-1999	0.6*	(0.08)	0.6*	(0.08)
25-29 & 2000-2007	0.4*	(0.07)	0.4*	(0.06)
30-34 & 1982-1990	0.7*	(0.12)	0.6*	(0.12)
30-34 & 1991-1999	0.5*	(0.09)	0.5*	(0.08)
30-34 & 2000-2007	0.4*	(0.06)	0.3*	(0.06)
35-39 & 1982-1990	0.6*	(0.14)	0.6*	(0.13)
35-39 & 1991-1999	0.4*	(0.09)	0.4*	(0.09)
35-39 & 2000-2007	0.3*	(0.06)	0.2*	(0.05)
40+ & 1982-1990	1.9*	(0.28)	3.1*	(0.43)
40+ & 1991-1999	1.5*	(0.18)	2.2*	(0.24)
Intercept	0.01*	(0.00)	0.01*	(0.00)
Pseudo R^2	0.23		0.19	
Observations	136833		173080.0	
Cases	11090		14206.0	

* $p < 0.05$

The predicted probabilities produced with this model are presented in Table 15 by age and compared with probabilities for the Gwembe Tonga women. Both approaches to contraception result in lower probabilities of being infertile than estimated with the Gwembe Tonga data. The difference between the approaches to contraception seem to have the most substantial effect in later age groups, with much lower estimates at later ages, even so that the probability is below 0.6 at the oldest age group.

Table 15. Predicted Probabilities of being infertile, with standard errors, for **Gwembe Tonga Women and Pooled DHS**

Age	Gwembe Tonga Women		Pooled DHS: Excluding Contraceptors		Pooled DHS: Contraceptors as Fertile	
20-24	0.07	(0.01)	0.04	(0.00)	0.03	(0.01)
25-29	0.18	(0.02)	0.13	(0.01)	0.09	(0.04)
30-34	0.24	(0.03)	0.22	(0.01)	0.16	(0.08)
35-39	0.39	(0.04)	0.39	(0.01)	0.29	(0.14)
40+	0.79	(0.03)	0.73	(0.01)	0.57	(0.29)

7. Discussion

In this analysis Larsen Menken's subsequently infertile estimate was used to estimate secondary sterility for Gwembe Tonga men and women as well as for four nationally representative samples from the DHS. Using a discrete time event analysis approach allowed the inclusion of some covariates for time, sex and interaction terms in addition to five-year age intervals. The estimates for these different populations and pooled populations served to produce population estimates of subfecundity for men; quantify the difference in subfecundity by sex among the Gwembe Tonga; explore the role of age on subfecundity between the sexes; and look at the role of time on subfecundity in Zambia. Additionally, using the DHS data, the effect of increasing contraception use on the measurement of subsequent infertility was explored. The analysis of the DHS datasets shows that while Gwembe Tonga estimates are higher than those estimated for all Zambian women, these estimates were still comparable. Some difference was expected given the variability across ethnic groups and regions found elsewhere in the world.

Male Subfecundity

This research demonstrates that male subfecundity can be analyzed using the same methods used for female subfecundity when male birth histories are collected and produced the first estimates of male subfecundity. This analysis shows that a measurable and sizable proportion of males experience secondary sterility in this population. These estimates are not identical to the estimates for women in the same population and react differently to covariates for age and time period, suggesting that measuring male subfecundity captures information about infertility (related to men) that is not captured or subsumed in the estimates based solely on women. Male subfecundity provides information about infertility in the population, likely biologic (as evidenced by age) and social (as evidenced by time), that is separate from the information provided through estimates based on women. In the pooled data set, the term for sex and terms interacting with sex were significant, indicating that sex was able to account for an important portion of the variance in subsequent infertility events. Most obviously, the prevalence of secondary sterility is lower for men than women. Male fecundity declines less rapidly with increased age and, in fact, subsequent infertility never becomes as widespread in men as it does in women, with substantially lower probabilities of being infertile for men at the oldest ages than for women at the oldest ages. Additionally, the effect of time period is different for men and women, likely reflecting different exposures and behaviors for the sexes over time.

However, measuring male subfecundity through birth histories poses several challenges. The most obvious potential challenge is that of paternity. While birth histories are quite likely to be capturing actual births to women, birth histories for men at best capture the socially assigned paternity, which may or may not correspond to actual paternity. Some practices among the Gwembe Tonga, such as “pro husbands”, where wives take a male relation of their husband to live with them when their husband travels and children can be claimed by the traveling husband (Mair, 1974), and increasing union dissolution may complicate how paternity is assigned or claimed. For an example of the potential problem, qualitative research on infertility experiences of women in Mozambique found that some women “cured” their infertility through extramarital sex, which allowed them to have children despite their husbands apparent infertility (Gerrits, 1997). Unfortunately, data are unavailable about the sexual relations prior to the recorded births; even with this limitation it is quite rare to have even reported paternity, given the relative unusualness of male birth histories. Related to this challenge is the problem of knowing which member of the couple is, in fact, infertile, the man, the woman or both. Similarly, estimates of women’s infertility do not indicate women that are subfecund but instead that couples are. When considering these estimates it is important to be aware that they are not additive. The men and women who are assigned a infertile indicator in many cases may be members of the same couple.

Male labor migration patterns are likely affecting inclusion in the risk set. Throughout this period Zambia experienced high rates of circular migration, with men traveling to the cities and mines for extended periods. In the earlier years of this study period, much of that travel would have been made by men alone, though in later years men were able to travel with their families (Ferguson, 1999). Ethnographic evidence indicates that labor migration decreased substantially in the Gwembe during the 1970s (Colson, 1971). Additionally, it is not unlikely that some of the effects of infertility, such as divorce, difficulty marrying and moving out of the area may impact men as much as, or more than, women, though male responses to subfecundity have been only limitedly researched (Dryer et al, 2004; Folkvord et al, 1995). Being generally more mobile, it could be that infertile men in this dataset are able to migrate or less likely to return for inclusion in the sample after labor migration. No data are available for whether men migrated or what may have occurred to them while they migrated.

Age and Subfecundity

The finding that fecundity declines with age (subfecundity increases with age) is not surprising and has been shown and discussed in detail elsewhere (see Menken, 1985). Age explains a substantial amount of the variance in these models and seems to be the primary driver of subfecundity in all the populations studied here, though the effects of age are much more pronounced in women than men and in particular in the last age groups. This analysis is the first to be able to verify this difference at the population level.

The two different approaches used for dealing with contraception use in the DHS datasets demonstrated that as contraception use increases the approach used becomes increasingly important given that the resulting estimates became increasingly disparate in the later surveys with higher contraception prevalence. This finding suggests that the utility of the infertile estimate based on birth histories may be limited for the 2007 survey.

Time Period and Subfecundity

For all models for all data sets, the last time period saw substantially and significantly increased odds of being infertile. For the Gwembe Tonga data, the time period from 1990-1999 saw much elevated odds of secondary sterility; DHS data showed elevated odds in 1990-1999 but also even higher odds of subsequent infertility for 2000-2007. As discussed in the introduction and background, the past fifty years have been tumultuous in Zambia, with substantial and sustained economic decline that has only recently begun to abate. The economic decline has been associated by some with a decline in fertility among younger women in Zambia, as families have adjusted fertility desires and practices because they are unable to afford more children in the bad economic times related to de-industrialization and the very negative effects of structural adjustment programs on the livelihoods of the poor (Potts and Marks, 2001). Adjustments to fertility desires that caused earlier stopping, extended birth intervals beyond five years, or increased spacing so that women and/or men reached age-associated subfecundability with fewer children would appear as infertile individuals in this measure and these estimates. Also related to the stagnating economy and structural adjustment programming was the stagnation of the Zambian health care system. McFalls and McFalls (1984) discuss at length the potential ways lack of medical care can contribute to the physiological causes of subfecundity, in particular obstetrical complications (effecting current pregnancy loss and future effects on sexual capacity, conceptive failure and pregnancy loss), absence of prenatal care (pregnancy loss), and untreated sexually transmitted infections (related to sexual capacity, conceptive failure and pregnancy loss).

Potentially most relevant to these observed time trends may be the explosion of the HIV epidemic in Zambia in the 1990s. Surveillance data indicate HIV rates among women seeking antenatal care over 25% in urban areas and over 10% in rural areas in 1994 and having declined only modestly by 2002 (UNAIDS, 2004). The 2007 DHS found an overall HIV prevalence of 16% for women (23% in urban areas; 11% in rural areas), with slightly lower rates for men (12% overall; 16% in urban areas; 10% in rural areas) (CSO, 2009). HIV has been associated with fertility declines caused by changes in sexual behaviors related to education about the disease and the disease itself, reduced fecundability of infected individuals as well as reduced sexual capacity related to illness, and at the population level declines in mortality based on high mortality among individuals of reproductive age (Gregson et al, 2003). While the population level changes affecting fertility should shrink the risk of? sex, the individual factors could easily be contributing to a measured increase in the proportion of the population that is infertile, particularly if HIV's effects worked synergistically with the effects of Zambia's prolonged, severe economic problems in the context of a deteriorating health care structure. Future research will investigate further this trend through the inclusion of covariates that attempt to capture these potential contributing factors with specific interest on HIV's role.

Contraception and Subfecundity Measurement

Contraception use is important for these estimates and is clearly seen in the divergence of the two approaches used for addressing contraception in the estimates as contraception use increased. Analysis of women's DHS data compared with estimates obtained for Gwembe Tonga women indicate that national subfecundity rates are quite similar to those of Gwembe Tonga women. Unfortunately, DHS datasets do not collect adequate birth data to construct infertile (or childlessness) estimates for men thus limiting analysis of infertility over time in the context of increasing contraception use to the women. Increasing contraception use among women in the population would complicate subfecundity estimates for men as they do for women and adjusting estimates for contraception use would require substantial levels of detail about men's partners' contraception use. Even if collected, the accuracy of men's recall about contraception use would be suspect. However, exploring the lower bound of infertility estimates, in which all contraception users are considered fertile, compared to estimates that exclude contraception users entirely, indicated that even with increases in contraception use, these measures are able to estimate a base level of subfecundity. In Zambia as of 2007, this lower bound of subfecundity indicates levels of infertility of note and though not as pronounced as the levels found in the "infertility belt" still within the levels of infertility found in other African countries from earlier data sets, which were well above the rates found for the Hutterites (Larsen, 1994). However, the increased use of contraception increases uncertainty of the estimate in a meaningful way as the discrepancy between the lower bound and the estimate for all non-contraceptors increases. With even higher contraception prevalence, this lower bound would likely fall to a level that would be effectively uninformative.

Measuring male subfecundity through birth histories has several substantial challenges, as discussed throughout this paper. In addition to problems of paternity and recall through birth histories, relative differentials in mobility may mean data collected through surveys are insufficient for making estimates. However, studies of male infertility based on medical diagnosis are subject to selection bias and require expensive diagnostics and use the medical definition (one year of trying to conceive), which makes estimates based on these studies of little use for demographic analyses (Menken, 1985). Though imperfect, the use of birth histories does provide an estimate of the population's subfecundity and some insight into the burden of infertility in the male population, how that differs from the burden experienced by the female population, and some insight to associations between male infertility and age and time. Data collection designed with the goal of estimating male infertility may be able to address some of these issues, investigating issues of paternity and accounting in design for migration trends.

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