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**Papers on Indirect Mortality Estimation & Analysis in Low-Resource Settings**

by

Romesh Mark Antony Silva

A dissertation submitted in partial satisfaction of the  
requirements for the degree of  
Doctor of Philosophy

in

Demography

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:

Professor John R. Wilmoth, Chair  
Professor Ronald D. Lee  
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Fall 2013

**Papers on Indirect Mortality Estimation & Analysis in Low-Resource Settings**

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University of California, Berkeley

Professor John R. Wilmoth, Chair

Policy makers in the health and development fields have established important goals and benchmarks for development progress, as showcased in the Declaration of Alma Ata (in 1978) and the Millennium Declaration (in 2000). Within these frameworks a clear and verifiable set of benchmarks were developed as a means of advancing transparency and accountability. Yet, often the data that are required to inform such evaluations, even for basic indicators such as child mortality, are lacking in low-income countries. This dissertation reviews the state of vital registration data systems in low-income countries, and then explores interim methods for measuring mortality when comprehensive civil registration systems are lacking. In particular, I evaluate the reliability of indirect methods to measure mortality rates under the age of 5 years by drawing on available data from Demographic and Health Surveys and from UNICEF's Multiple Indicator Cluster Surveys. I also carry out a validation study of indirect adult mortality estimation methods using historical population registers from northeast China, and assess the quality of mortality data collected at a demographic surveillance site in South Africa. The analysis demonstrates that indirect estimates, especially when adjustments are made to address simplifying assumptions, are generally consistent with adjusted direct estimates (in the case of child mortality) and life table estimates (in the case of adult mortality estimates). These results suggest that indirect estimates have a limited use in low-income countries, namely for populations that have experienced either smooth mortality declines or only short periods of excess mortality in their recent past. When examining data quality at the Agincourt demographic surveillance site, I found that such data provide a strong basis for the examination of health and mortality transitions in low-income countries given that they are less vulnerable to many of the data errors found in household surveys and population censuses in low-income countries. These findings underline the limitations of indirect methods, the promise of demographic surveillance systems as a valuable data source, and the critical importance of sustained improvements to civil registration systems.

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# Chapter 1

## Introduction

### 1.1 Motivation and Specific Aims

This dissertation has two broad aims. The first is to explore indirect mortality estimation methods, by examining their performance in a broad range of settings with diverse sources of data and focusing particularly on the reliability and validity of such estimation methods when some of their simplifying assumptions are violated in real-world settings. The second aim is to develop refinements to the classical indirect estimation methods so that they can be used effectively in situations where application of the classical methods are vulnerable to considerable bias.

Over the years there have been a number of international efforts to focus and advance efforts on advancing public health particularly in low-income countries. These efforts date back to the declaration of Alma Alta that organized policy and actions around a target of “Health for All” in the form of attainment by all peoples of the world by the year 2000 of a level of health that would permit them to lead a socially and economic productive life (International Conference on Primary Health Care, 1978). Currently world leaders are coalescing around the development goals outlined in the United Nations Millennium Declaration (commonly referred to as “the Millennium Development Goals”), some of which include mortality as an important indicator of progress (United Nations, 2000). As a result mortality measurement has been a critical component in the assessment of health and development progress.

The lack of availability and variable quality of mortality data in contemporary developing country populations and many historical populations often poses many challenges. United Nations (2002); Bhat (1995) has noted that incomplete civil registration systems, inaccurate census enumerations, as well as misreporting of ages in both population and death data pose particular difficulties to assessing mortality trends and monitoring public health. In response to these challenges of inadequate civil registration systems, Henry and Brass pioneered a suite of indirect estimation

methods to estimate mortality from summary information on survival of close relatives (Henry, 1960; Brass, 1964b; Brass et al., 1968; Brass, 1971b). These methods have been progressively refined and extended over the last five decades (Trussell, 1975; Sullivan, 1972; Rajaratnam et al., 2010c; Timaeus, 1992; Gakidou and King, 2006) Additional indirect approaches have been developed for adult mortality estimation that make use of successive censuses and death registration data (Brass, 1975; Hill, 1987; Bennett and Horiuchi, 1981, 1984). Further, in recognizing the important effect of age, demographers have also developed model life table methods to infer relationships between mortality indicators at different ages for a population with limited or poor empirical data. Preston (1976) noted how such age patterns of mortality are reflective of the relative importance of specific causes of death at different age groups - for example, infectious diseases being particularly prominent during infancy and early childhood, accidents and injuries more common during early adulthood years, while degenerative diseases being prominent at older ages. Thus age specific mortality rates themselves can yield important insights into the underlying disease patterns and mortality causes affecting a population. Coale and Demeny (1966); United Nations (1982) developed the first model life tables using early forms of principal component analysis to identify distinct “families” of mortality age patterns. More recently, Murray et al. (2003); Wilmoth et al. (2012), moving away from discrete families of model age patterns, have developed continuous mortality models that are underpinned by reasonably regular relationships between mortality between birth and age five and adult mortality (ie mortality between age 15 and around 50 or 60).

## 1.2 Theoretical and Practical Significance

Paradoxically, populations that tend to have high mortality tend to be those where reliable mortality data are least available. In the absence of national-level mortality registration or surveillance data, analysts rely heavily on ad-hoc survey data and decennial population censuses. Thus there is considerable uncertainty in our understanding of the levels, trends and nature of mortality and underlying health dynamics for most developing countries. This makes the practical yet important task of engaging basic questions of program evaluation and resource allocation particularly challenging.

On the theoretical level, the lack of high quality mortality data and the reliance on ad-hoc, indirect methods make it difficult to empirically assess the plausibility of some of the fundamental aspects of the demographic and epidemiological transition. Omran (1971), in his classic article on a theory of the epidemiology of population change, outlined a framework for the development process that accompanies increased population growth resulting from innovation in disease management and control and is often followed by population growth stabilising due to subsequent fertility decline.

Omran (1971) theorized that the epidemiological transition is characterised by three distinct phases: (i) *the age of pestilence and famine*, during which mortality is high and fluctuating, with an average life expectancy under 30 years, (ii) the *age of receding pandemics*, during which life expectancy rises considerably, from under 30 to over 50, and (iii) the *age of degenerative and man-made diseases*, during which the rate of the mortality decrease slows, and infectious diseases are replaced by degenerative and man-made diseases as the most common cause of death.

Over the years Omran's framework has been progressively revised and extended, as new empirical evidence has become available. Olshansky and Ault (1986), in an attempt to incorporate gains resulting from the "cardiovascular revolution," proposed a fourth phase of the transition dubbed *the age of delayed degenerative diseases* in which rapid mortality declines in advanced ages are caused by a postponement of the ages at which degenerative diseases tend to kill. Olshansky et al. (1998), responding to the inadequacy of Omran's original framework to recent population dynamics in many sub-Saharan African countries, proposed a fifth stage of transition in which there is a re-emergence of infectious diseases and the introduction of new diseases such as HIV/AIDS.

More recently, Caselli et al. (2002), noting the considerable empirical departures from the phases of Omran's epidemiological transition theory, have critiqued the basic premise of continuous convergence of life expectancy in Omran's theory of epidemiological transition. These authors have emphasised that divergence in health trajectories has dominated the post-1980s periods - in which the HIV/AIDS epidemic, political and social disruptions such as the break-up of the former Soviet Union and protracted armed conflict have played a substantial role. These debates underline the importance of high-quality empirical data and reliable mortality estimation to advance the development and refinement of our understanding of historical and contemporary epidemiological and demographic processes.

## 1.3 Data & Methods

In this dissertation, I use data from a wide range of sources including large international household survey programs (namely the Demographic and Health Surveys, and Unicef's Multiple Indicator Cluster Survey program), a household registration system from a Northeastern Chinese province covering the 19th and early 20th century, and a demographic surveillance site in South Africa.

In analyzing these data, I draw heavily on quantitative methods from the fields of demography and statistics. In particular, I use the classical direct and indirect methods to analyze the available data and make a series of adjustments for data errors and violations of the underlying assumptions

of the methods. I also investigate use and extend demographic and statistical diagnostic methods to assess the quality of mortality data to examine its effect on mortality estimation.

## **1.4 Structure of the Dissertation**

This dissertation starts with an introduction to the state of mortality data sources and mortality estimation methods, noting our persistent reliance on household surveys and decennial censuses and work-around estimation methods. My overall focus is on indirect mortality estimation methods and their viability as interim approaches to mortality estimation while civil registration continue to be developed and enhanced.

In chapter 3, I review direct and indirect estimation methods that are widely used to estimate under five mortality rates in developing countries when high quality vital registration information is unavailable. I use data from Demographic and Health Surveys from West Africa, East Africa, Latin America and South and Southeast Asia. I quantify the difference between direct and indirect estimates, analyze the nature of the data quality issues associated with full birth histories, note the relative effects of these errors, and test whether these errors explain observed differences between direct and indirect estimates. My focus is on situations where direct and indirect estimates are derived from a single data source are examined. This analysis is limited by the lack of validation data in these settings. Yet, my findings suggest that the observed differences between direct and indirect estimates are mostly explained by some of the simplifying assumptions of the summary birth history methods and data errors in full birth histories. In Chapter 4, I briefly examine the case when direct and indirect estimates are derived from different data sources and outline the need for additional research in this area.

With child mortality decreasing, an increasing proportion of all deaths in the developing world will occur at adult ages in the coming decades. However, vital registration systems in many developing countries are incomplete and unreliable, and are thus not able to provide a strong basis for the estimation of adult mortality. As a result, demographers have had to rely on work-around methods such as death distribution methods (eg the generalized growth-balanced method and synthetic extinct generations method) as well as survey methods that use data on the survivorship of close relatives (such as the sibling-survival method and orphanhood method). Yet the reliability and validity of these methods is not well understood. In chapter 5, I use high quality household registration data from Liaoning province in China to assess the validity and reliability of these two broad adult mortality estimation methods. I use the household registration data as a validation dataset to gain insights into the performance of these adult mortality estimation methods in a high mortality population.

#### *1.4. STRUCTURE OF THE DISSERTATION*

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In chapter 6, I draw heavily on methods developed at the Human Mortality Database (HMD). I adapt the HMD data quality assessment framework to assess the quality of demographic surveillance site data being collected in developing countries. These data are thought to be the highest quality contemporary mortality data on developing country populations, albeit at the subnational level. Yet these data have not been widely analyzed. Hence, I present a data quality assessment of the data collected at the Agincourt DSS site in South Africa. This assessment is intended to explore the applicability of HMD-style data quality assessments to contemporary DSS data and help facilitate data quality comparisons with mortality series and resulting estimates from high income countries.

In chapter 7, I conclude by providing an overview of the main findings from this dissertation and then discuss potential future research directions to advance mortality estimation approaches in low resource settings.



## Chapter 2

# Background

In this background chapter, I review the importance of mortality as a measure of population health and the sources of data that social scientists and public health researchers have used in its study. I focus particular attention on civil registration systems – both for their evaluative potential and their instrumental importance for both the individual and society. Despite this, there has been a stagnation in the development of civil registration systems in low-income countries, where alternative data sources and work around methods have been promoted sometimes at the expense of civil registration system development and maintenance. I use Sen’s capabilities approach to draw particular attention to the potential instrumental effects of civil registration systems and also note how civil registration systems, used in combination with other data systems such as surveys and censuses, have yielded important insights into population health. In conclusion, I note the vital importance of civil registration and the importance of integrating lessons learned from the development and use of civil registration systems in the shaping of the post-2015 development agenda.

### 2.1 Why Mortality & Mortality Measurement Matter?

Mortality data are important in the measurement of disease and population health, and thus critical in the planning of public health interventions. Studying trends in mortality over time helps to evaluate how the health status of the population is changing and assists in the evaluation of the health system.

Mortality data also provide a basis for investigating the incidence of disease, its severity and the quality of life prior to death. The patterns of mortality in the community disaggregated by cause of death, age, sex, population subgroup, and geographic location, inform the work of epidemiologists, medical clinicians, health policy analysts, as well as administrators. The measurement and comparative analysis of mortality rates for different populations helps to illuminate health differences

## 2.2. OVERVIEW OF POPULATION DATA SYSTEMS USED FOR MORTALITY

MEASUREMENT among different groups of people. It may also help to highlight differences and guide analysts to understand what drives health disparities.

## 2.2 Overview of Population Data Systems Used for Mortality Measurement

Vital statistics systems are at the core of population studies and demography, as they focus on the accurate recording of core vital events associated with an “individual’s entrance into or departure from life together with changes in civil status” (Van de Walle, 1982). A vital statistics system, by definition, encompasses “the total process of (a) collecting information by civil registration or enumeration on the frequency of occurrence of specified and defined vital events, as well as relevant characteristics of the events themselves and of the person or persons concerned, and (b) compiling, processing, analyzing, evaluating, presenting and disseminating these data in statistical form” (United Nations, 2001).

Governments, international organizations and academic researchers use six main data sources when assessing mortality levels and trends at the national and subnational level: (i) civil registration systems, (ii) population censuses, (iii) household surveys, (iv) population registers, (v) sample registration systems, and (vi) demographic surveillance systems. Civil registration is universally recognized as the most ideal source for the regular derivation of vital statistics, including mortality rates (United Nations, 2001), as it entails the continuous, permanent, compulsory and universal recording of the occurrence and characteristics of vital events. Civil registration systems are run by a public institution and used for legally registering and recording data on vital events related to the civil status of the population, including births, deaths, causes of death, marriages and divorces, on a continuous basis as provided by the laws and regulations of the country. The basic civil registration functions include recording vital events, storing, safe-keeping and retrieval of vital records, protection of confidentiality, certificate issuing and other customer services, recording and reporting information on vital events for statistical purposes, and providing reliable and timely information and data to other government agencies. Thus, one of the most important attributes of civil registration systems is that they concurrently serve important legal, administrative, and statistical purposes (in contrast to other sources).

Where civil registration is lacking or incomplete, population censuses and household surveys are widely used as interim measures for the derivation of vital statistics. Population censuses, by themselves, are sufficient for the calculation of population rates and the statistical estimation of population parameters for small subnational areas. However, given their large costs, are only usually carried out every 10-years and are not able to provide regular, timely insights into population dynamics. Surveys are subject to an array of sampling and non-sampling errors and are usually

not adequate for disaggregated analysis for small subnational areas. However, given their versatility, surveys have the ability to provide detailed information about a range of socio-economic characteristics of the population, as only a small fraction of the total population is actually sampled.

Sample registration systems (SRS) have been instituted in China and India, in both cases, as an interim measure to generate vital statistics while the civil registration systems there are further developed. In India, the SRS is based on a system of dual recording of births and deaths in fairly representative sample units spread all over the country (Mahapatra and Rao, 2001). Whereas, the Chinese SRS operates more like a wide-area disease surveillance system through which deaths are recorded by health care facilities (for deaths occurring in clinical facilities) and village health workers (for deaths that occur at home) (Yang et al., 2005). These systems provide annual estimates of levels, patterns, and causes of mortality that are representative of the national population and major provinces/states (Mathers et al., 2005). However, they are subject to sampling errors and non-sampling content errors (about the cause of death) as the recording of death information is regularly preformed by someone other than a health professional.

Demographic surveillance sites (DSS) monitor and record demographic and health characteristics of a population living in a well-defined geographic area (usually of around 10,000 - 20,000 households). Most of these sites were initially set up around a longitudinal cohort study (associated with a specific health intervention) and have subsequently been extended as a platform for long-term continuous demographic surveillance (Ye et al., 2012). Vital events are recorded through regular censuses, at least annually but at some sites as regularly as three times per year. However, as most deaths occur outside the formal health care system, verbal autopsy methods are frequently used to classify cause of death (Baiden et al., 2006). A critical limitation of DSSs as a source of vital statistics is that such sites only cover a small subnational area, thus making generalization of findings to a broader national population difficult.

## 2.3 Historical Origins of Modern Civil Registration

Demographers and epidemiologists have both noted the central importance that the study of mortality has played in understanding public health challenges and crafting appropriate policy responses. This tradition of the formal, quantitative study of mortality and population dynamics dates back at least to the contributions of John Graunt in 17<sup>th</sup> century London. This important work is often associated with the founding of modern demography. Graunt (1662), drawing on the registration of deaths documented in the *Bills of Mortality* (weekly lists of deaths in the city of London), organized the data by age and observed notable statistical regularities in probabilities of survival to each age, constructed the first known life tables, estimated the population size of London, described migration and fertility dynamics, and systematically analyzed death registration data by

reported causes of death.<sup>1</sup> The motivation for Graunt's analysis came from the business community in London who were interested in understanding the effect of the plague on demand for their products and services (Hald, 2005). Arguably, the most important contributions of Graunt were to identify the importance of death registration data and to organize his analysis around survivorship by age and the causes of death in the underlying data. Given the crudeness of his data, whose death categorizations included "fever," "dead in the street," "chrisomes, and infants," "cancers," "king's evil," "dropsies," and "killed by several accidents," Graunt perhaps was one of the first pioneers in using indirect methods to evaluate the quality of death registration data.

The importance of death registration in England culminated in William Farr's founding of the modern English vital statistics system in 1838, through his work as as compiler of abstracts at the General Registrar's Office. Farr conceptualized mortality as an important measure of population health. He drew heavily on the vital registration system in spatially mapping population health outcomes as an evidentiary basis to guide public sanitation officers, pioneered the study of mortality by occupational classes, used death registration to identify the spatial distribution of cholera, used "health districts" as a benchmarks to estimate excess mortality in other districts (Farr, 1837; Eyler, 1979). His spatial analysis of age-specific mortality rate patterns across rural and urban communities in the UK was particularly innovative in that it combined vital registration data with records from the 1841 population census - thus providing early evidence of the analytical insights possible when combining vital registration data with those from complementary population data systems. The breadth and rigor of Farr's work in advancing a robust evidence base for public health policy and action have been noted as being instrumental in the improvement of living conditions, particularly in urban areas, during the 19th century in Great Britain (Szreter, 1991).

## 2.4 Human Rights Underpinnings of Civil Registration

Universal civil registration is crucial, not just to guide and evaluate public health programs, but also because it contributes to the promotion and protection of human rights. The right of each individual to identity and recognition of one's personhood is explicitly recognized in the core international human rights instruments, specifically the International Covenant on Civil and Political Rights and the International Convention on the Rights of the Child. For example, article 24(ii) of the International Covenant on Civil and Political Rights proclaims that "Every child shall be registered immediately after birth and shall have a name." (United Nations, 1966a). The process of birth registration within a civil registration system legally acknowledges the existence of the person, enables the child to obtain a birth certificate, establishes the child's family ties, and tracks

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<sup>1</sup>The compilation of weekly bills of mortality date back to the early 15th century in some Italian cities and parts of continental Europe. However, Graunt was the first to apply formal demographic methods to study these type of data.

#### 2.4. HUMAN RIGHTS UNDERPINNINGS OF CIVIL REGISTRATION

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major life events from live birth to marriage and death.

In Table 2.1, I note that, although registration of vital events is recognized in a number of different international human rights conventions, the way in which the importance of registration is recognized varies. Rights to registration of birth and marriage are *explicitly* recognized. In contrast, the right to registration of death and divorce are only *implicitly* recognized in core international conventions.

Table 2.1: Rights to Registration of Vital Events and International Human Rights Instruments

No.	Human Right	Relevant International Instrument(s)	Reference	Role of Vital Registration
1	Right to Birth Registration	International Covenant on Civil and Political Rights, Article 24(2) (United Nations, 1966a).  International Convention on the Rights of the Child, Article 7 (United Nations, 1989).	Explicit	Legal record of child's birth, and thus basis for basic proof of identity, age, nationality, etc.  Official statistical record of live birth
2	Right to Death Registration	ICESCR, Article 12.2 (United Nations, 1966b) (provision for the reduction of infant mortality).	Implicit	Monitoring the provision for reduction of infant mortality (as stated in the ICESCR)  Respect for related economic, social and cultural rights (eg right to inherit, right to social security, etc.)
3	Right to Fetal Death Registration	ICESCR, Article 12.2(a) (United Nations, 1966b).	Implicit	Provision for reduction of the still-birth rate
4	Right to Marriage Registration	CEDAW, Article 6.3 (United Nations, 1979).  Convention on Consent to Marriage, Minimum Age for Marriage and Registration of Marriage, Article 3	Explicit	Legal Proof for occurrence and characteristics of marriage - specifically for protecting against forced marriage practices and marriage of legal minors, as well as provisioning for rights to inheritance, and other associated economics, social, and cultural rights.

In addition to the right to registration of vital events being recognized in core international human rights covenants, the promotion and protection of many basic human rights that are included in core international human rights instruments are contingent on an individual being able to prove their identity, age, marital status, nationality, etc. Civil registration safeguards individual human rights. It does this by establishing identity, parental relationship, inheritance and citizenship, and provides eligibility data for social benefits and age-based benefits, such as school entry, the right to work and a driver's license, as well as the right to vote. As shown in Table 2.4, most of these rights are associated with Article 11(1) of the International Covenant on Economic, Social and Cultural Rights in which "the right of everyone to an adequate standard of living for himself and his family" is recognized (United Nations, 1966b). As Table 2.4 shows, the international human rights conventions identify birth registration as having a central role in facilitating the recognition of key rights associated with education, health care, social welfare, universal suffrage, marriage, and marriage. Marriage and death registration are recognized as playing important roles, but not to the same extent of facilitating rights of individuals. For example, the implicit references to death registration in the International Covenant on Economic, Social, and Cultural Rights are not geared towards an individual exercising a specific right, but rather facilitating public action (by state and civil society actors) in the provision of suitable public and clinical health services. Further, clear benchmarks in terms of mortality are only mentioned with respect to foetal, infant and child mortality, with no mention made of premature adult mortality.

Table 2.2: Linkage Between Basic Human Rights in International Human Rights Instruments and Civil Registration

No.	Human Right	Birth	Marriage	Death	International Instrument	Linkage
1	Right to an Identity	X			Article 24(2), ICCPR., Article 7, CRC .	Official birth record is the foremost legal document that can certify true, legal name of an individual
2	Right to a nationality	X			Article 15(1), UDHR., Article 24(3), ICCPR.	Birth record provides proof for eligibility to vote, hold political office, obtain a passport, etc.
3	Right to Parental Support and Protection	X			Article 24(1)	Enforcement of duties parents have to their non-adult offspring.
4	Right of Juveniles for Special Treatment before the law	X	X		Article 14(4), ICCPR., Article 10(2)(b), ICCPR	Affording of special treatment of minors before the law and the prohibition of the death penalty against minors.
5	Right to Protection from Child Marriage	X	X		Article 16(1), UDHR., Article 23(2), ICCPR., Article 10(1), ICESCR	Certification of age to guard against child marriage practices.
6	Right to Protection from Forced Marriage		X		Article 16(2), UDHR	Proof of “free and full consent”
7	Right to Education	X			Article 13(1), ICESCR, Article 26(1), UDHR	Enforcement of universal, free access to primary education
8	Right to Work	X			Article 6(1), ICESCR.	Proof of age and nationality (for some employment opportunities in government sector)

Continued on next page



Table 2.2—continued from previous page

No.	Human Right	Birth	Marriage	Death	International Instrument	Linkage
9	Right to Protection from Child Labor	X			Article 32(2)(2), CRC.	Enforcement of minimum age employment laws
10	Right to Food and Nutrition	X		X	Article 25(1), UDHR., Article 11(1), ICESCR	Aide assessment of supplemental maternal/child feeding programs
11	Right to Health	X		X	Article 25(1), UDHR., Article 12, ICESCR	Provision for reduction of stillbirth rate and infant mortality rate. Prevention, treatment, and control of epidemics.
12	Right to Housing	X	X		Article 25(1), UDHR., Article 11(1), ICESCR	Evaluation of eligibility for state subsidised housing.
13	Right to Inherit	X	X	X	Article 5(d), CERD., Article 6(1)(a), CEDAW	Proof of parental filiation required to expedite inheritance rights.
14	Right to Marry	X	X		Article 16(1), UDHR., Article 23(2), ICCPR	Verification of age eligibility and non-consanguinity.
15	Right to Own Property	X			Article 17(1), UDHR., Article 6(1), CEDAW.	Proof of identity for exercising right to own property.
16	Right to migrate	X			Article 13(2), UDHR., Article 12(2), ICCPR	Freedom of movement (across national border) usually requires provision of a passport which, in turn, requires proof of identity.
Continued on next page						

Table 2.2–continued from previous page

No.	Human Right	Birth	Marriage	Death	International Instrument	Linkage
17	Right to vote and be elected	X			Article 21(3), UDHR., Article 25(b), ICCPR.	Verification of age and citizenship eligibility for voting or holding of representative office.

Death registration is implicitly recognized in the Universal Declaration of Human Rights (UDHR) and the International Covenant on Economic, Social, and Cultural Rights (ICESCR) - the two international human rights covenants that are the least legally binding on UN member states. The UDHR is a declaration, and thus not a legally enforceable treaty but rather a "common standard of achievement for all peoples and all nations" (United Nations, 1948). The ICESCR, like other international treaties and conventions, is legally binding and the parties (ie. member states) undertake to respect, ensure and take steps for the full achievement of a wide range of rights therein. However, unlike the other human treaties (eg the International Covenant of Civil and Political Rights, the Convention on the Rights of the Child, etc), the ICESCR imposes a lesser duty on state parties than other human rights conventions in the form of the *Principle of Progressive Realization*. This principle imposes a duty on all parties "to take steps, [...], to the maximum of its available resources, with a view to achieving progressively the full realization of the rights recognized" in the ICESCR. This principle differs from that of the ICCPR and other human rights conventions, which oblige parties to "respect and to ensure to all individuals within its territory and subject to its jurisdiction the rights in that Convention" (United Nations, 1966a). The principle of progressive realization acknowledges that some of the rights (such as the right to health) are difficult to achieve in a short period of time, and that states may be subject to resource constraints, but requires them to act as best they can within their means. The requirement to "take steps" imposes a continuing obligation to work towards the realisation of those rights, but does not prescribe what constitutes adequate steps or reasonable progress.

## 2.5 Civil Registration & Sen's Capabilities Approach

In order to more fully appreciate the instrumental nature of civil registration, I review civil registration through the lens of the capabilities approach. Sen introduced this approach as part of the Tanner lectures, and progressively developed and refined them over time (Sen, 1976, 1980, 1981, 1999). This approach was initially developed in specific response to analytical work to understand extreme deprivation, most notably in the form of famine crises.

The capabilities approach focuses the evaluation of development progress around what people are actually able to be and do. It's specific focus is the quality of life that individuals are able to achieve. This is in contrast to utilitarian or commodity based approaches - whose locus of primary concern are more towards subjective judgements and individual income or asset wealth. When considering civil registration, such basic documentation of the person can play a basic yet important role in protecting and promoting the basic human rights of the individual.

The notion of capabilities is strongly linked to the Aristotelean notion of "eudaimonia" or "human flourishing." In developing the capability approach, Sen sought to address key challenges to

evaluating development progress (and, more specifically, understand key contributing factors to extreme deprivation), namely that:

- differing abilities across individuals can convert the same resources into valuable functionings,
- evaluation needs to not only focus on subjective mental metrics, but also consider objective judgments,
- evaluation must be sensitive to both actual achievements (“functionings”) and effective freedom (“capability”).

The entitlement approach and capabilities framework to deprivation and famine focuses on people having or not having enough command over food as distinct from there being or not being enough food to be eaten. Sen's work was developed in response to famine demography literature that characterized the cause of famines as primarily being a decline in food availability (Arnold, 1988). He noted that this seemingly simple explanation did not fit the empirical reality of why only particular subpopulations (such as landless laborers and agricultural workers) were affected by famines, while other parts of the population were relatively unaffected. The entitlement approach provided a basis for considering the multidimensional causes of famine and focusing on a change in people's endowments and/or entitlement mappings.

Sen's exchange entitlement framework builds on three critical categories: the endowment set, the entitlement-mapping, and the entitlement set. The endowment set is the combination of all resources legally owned by a person and can include both tangible assets (such as land, animals, vehicles, etc.) and intangibles (for example knowledge, technical skills, labor power, etc.). The entitlement set is the set of all *possible* combinations of goods and services that a person can legally obtain through the use of the resources in their endowment set. The entitlement mapping is defined as the relationship between the endowment set and the entitlement set. This mapping broadly shows the possible trajectories for conversion of raw resources in one's endowment set into possible goods and services in one's entitlement set. Figure 2.1 provides a visual representation of the relation between these three categories.

In developing the entitlement approach, Sen framed famine as an entitlement failure that usually stems from a change in people's endowments and/or entitlement mappings. Thus the entitlement framework provides a useful organizing framework for the study of the dynamics of famine. In extending this framework to population health dynamics, we can view population health deprivations as being essentially characterized by entitlement failures, as opposed to simply a shortfall in aggregate health supply. By framing population health within a human rights framework and

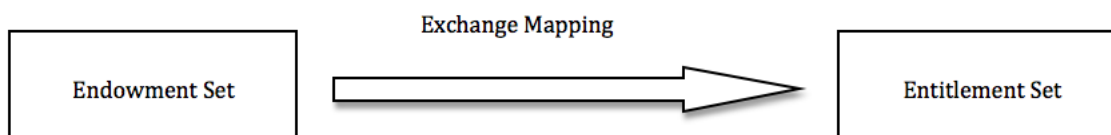


Figure 2.1: Visual Representation of Relationship between Endowment Set, Entitlement Set, and Entitlement Mapping in Sen's Capabilities Framework

recognizing the centrality of civil registration, we are able to tease out the interconnectedness of how failures in the realization or protection of basic human rights leads to reduced human flourishing. In short, this framework helps unpack how legal and administrative systems have the potential to strengthen political freedoms, economic facilities, social opportunities, transparency guarantees and social protections of individuals. The two principal strengths of the entitlement approach are that it is conducive to analysis that is sensitive to plurality of causes and asymmetries in impact of demographic and health consequences.

Within this framework, a person suffers from the failure of health entitlement when their entitlement set does not contain basic health to avoid premature death, without non-entitlement transfers. So, no matter how they reallocate their resources to obtain basic health, the individual cannot attain a minimum amount needed to escape chronic or acute ill health. A health crisis results when a large number of individuals within the community suffer from such entitlement failures at the same time.

## 2.6 Current State of Civil Registration Around the World

Despite mortality widely being recognized as an important population health indicator and civil registration (in the form of death registration with medically certified cause of death evaluations) being the preferred data source for mortality, civil registration coverage remains low. United Nations (2008b) reported that, of the countries and areas that it monitors, only 60% of the 230 countries and areas register more than 90% of births. Whereas, for death registration, only 47% of the countries and areas have at least 90% coverage.

Boerma and Stansfield (2007) have, as shown in Figure 2.2, observed that investment and advancement in household surveys in low-income countries has far outpaced the development and enhancement of civil registration systems. Thus governments, donors and international partners,

## 2.6. CURRENT STATE OF CIVIL REGISTRATION AROUND THE WORLD

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in focusing on the needs for accountability and evaluation around initiatives such as the Alma Ata Declaration, Millennium Development Goals, and ICPD-2015 process have prioritized short-term evaluative needs over longer-term development of administrative systems (such as civil registration) that serve both instrumental as well as evaluative purposes. As a result, sample-based data sources and work-around methods that were originally developed as interim approaches have started to take on a more of a role as replacement for civil registration systems (Hill, 2006).

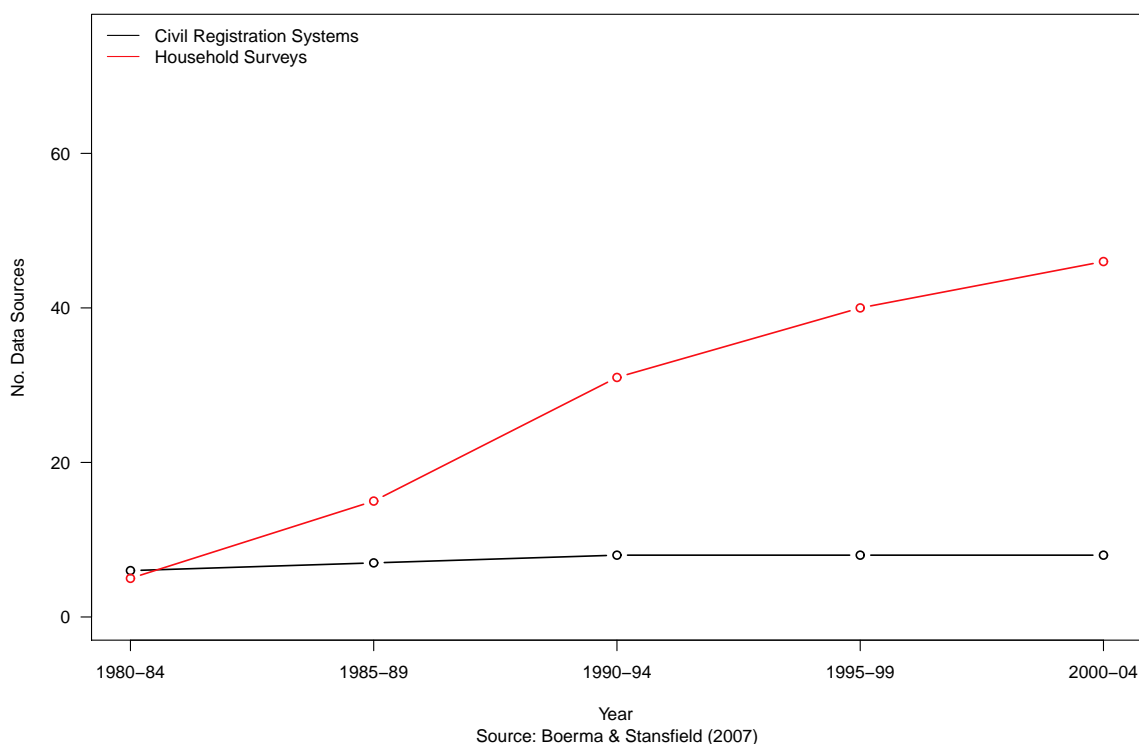


Figure 2.2: Mortality data collection and reporting by source in 57 low-income countries, 1980-2004

Even when there are good analytical opportunities to make use of complete civil registration, they are not always taken. Garenne (2002) notes that despite the city of Antananaviro, Madagascar having a high quality civil registration system since 1921, it experienced a famine in the mid 1980s that remained hidden for decades. Recent analyses of the death registration data by Waltisperger and Mesle (2005); Waltisperger et al. (1998) revealed that during 1985-86 mortality levels rapidly increased, and life expectancy fell from 59.4 years in 1975, to 49 years in 1986. During this period,

adult mortality was high - particularly for males - and the cause of death profile was characterized by mortality from malnutrition/starvation. This mortality profile, in which 1.3% of the population died as a result of famine-related causes, is consistent with that of a low intensity famine. Yet, despite the mortality consequences of this famine being systematically recorded by the death registration in real time, these data were not analyzed and the famine broadly discussed until almost twenty years later.

In India, currently the government and international agencies rely almost exclusively on the Sample Registration System, when compiling summary measures of mortality (eg  ${}_5q_0$ ,  ${}_{45}q_{15}$  and  $e_0$ ) (United Nations, 2012; Registrar General of India, 2006). However, some states (such as Kerala and Karnataka) have civil registration completeness rates of over 90% - the rough international minimum standard for “completeness” when assessing the adequacy of civil registration data for the production of vital statistics. Yet, the civil registration data from states with high coverage are not used in the official compilation of vital statistics for India.

Despite (or perhaps because of) its wide-ranging benefits and cross-cutting nature, civil registration has received limited and somewhat uncoordinated support from international organizations. At the international level, the primary responsibility for strengthening vital statistics system has been assumed by the United Nations Statistical Commission. The associated technical assistance to member states has been the domain of the United Statistics Division and the respective regional commissions in the Asia Pacific, Western Asia, Latin America and the Caribbean, Europe, and Africa. However, the focus of the UN Statistics Division has been primarily on compilation of vital statistics, to facilitate a robust international comparison framework, rather than the enhancement of basic civil registration process and systems. UNICEF has noted the connection between universal birth registration, human rights and the realization of maternal and child health (UNICEF, 2005). However, UNICEF’s programmatic work in this area has focused singularly on birth registration (without addressing the importance death registration) and has lacked coordination with other international agencies (such as the World Health Organization, UNFPA, United Nations Statistics Division, and United Nations Development Programme).

Challenges at the international level need to be managed along with challenges at the national and subnational levels for different states. Civil registration, given its cross-cutting nature which spans the areas of governance, health, economics, and the law poses notable challenges of coordination for governments. Further, the nature of civil registration involves decentralized collection and management of vital records, but centralized coordination and compilation of vital statistics - thus requiring continuous coordination between local, regional, and national levels of government. The government of India, in noting the critical importance of identity registration in enhancing human development, has identified technology as fundamental in its efforts to implement the world’s largest identity registration project called “Aadhar.” This project is motivated by the need for standardization and securitization of identity records in India. Currently, to support governance,

economic and social processes individuals rely on a myriad of different registration documents and databases (eg ration card systems, drivers license programs, voter registration cards, etc) while the government makes little use of administrative data systems for population health measurement and instead relies on the National Family Health Survey, decennial census, and sample registration system. The Aadhar project has been designed to use new biometric technology to create a unique identifier for every individual in India (Nadhamuni, 2012). Low-cost biometric technology is key in facilitating universal access to identity registration and reliable authentication (to ensure that the right individual is recognized when providing a service or entitlement). Further, such biometric technology provides a means of unique identification through the use of iris scanning and finger printing technology.<sup>2</sup> However, Aadhar is focused mostly on identity registration to facilitate broader inclusiveness in India's burgeoning market economy and formal banking sector. Its current design does not incorporate death registration and its birth registration procedures have not been integrated and streamlined into India's existing birth registration procedures.<sup>3</sup> Hence, despite the careful work in adapting new technologies to advance identity registration in India, there has been limited work in integrating this new system with India's established civil registration process.

Internationally, there continues to be a large emphasis on the support and development of sample-based systems. Setel et al. (2006), citing recent experiences in China and India, have emphasized the development of sample registration systems as "an affordable, cost-effective, and sustainable short- and medium-term solution" to population health monitoring challenges. Further, Sankoh and Byass (2012) have mused that such wide-area demographic surveillance "may become a more common model as countries move towards universal individual registration." Sample registration systems certainly do combine some of the evaluative strengths of population censuses, household surveys and demographic surveillance (Begg et al., 2005; Rao, 2011). However, they do lack the underlying legal and governance foundation of civil registration and any resulting mortality assessments are vulnerable to sampling and non-sampling errors (particularly for cause of death data collected through verbal autopsy procedures). To date, in low-income countries civil registration data has been used for statistical purposes in only very limited ways: mainly to assess the completeness of sample registration systems. As such, there is a need for research into how best to enhance existing civil registration systems and combine data from multiple sources (eg incomplete civil registration systems, sample registration systems, population censuses and household surveys) to compile reliable vital statistics. A focus on integration of multiple data sources, with a recognition that civil registration is the foundation of a strong vital statistics systems, is more likely to lead to a healthier balance and be less vulnerable to over-reliance on interim systems and methods at the expense of basic development of civil registration. Multiple data sources are needed, given that no single data source or single method is adequate, to better understand the

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<sup>2</sup>See Breckenridge (2005) for discussion about the potential privacy and confidentiality risks associated with the use of such technology in centralized computer databases.

<sup>3</sup>See <http://uidai.gov.in>.



strengths and limitations of different data sources and estimation methods. But recognition of civil registration's central role in health monitoring systems is also required to facilitate both evaluative as well as instrumental effects that are possible from improved health information systems.

Given the notable challenges of establishment and maintenance of civil registration systems in low-income countries (where transportation and communications infrastructure are often underdeveloped), the establishment costs have oft been cited as a critical barrier to universal civil registration. However, recent estimates for achieving civil registration across the African continent have been estimated at US\$80 million per year – a cost of approximately 10 cents per capita (MDG Africa Steering Group, 2008). AbouZahr et al. (2010) have noted that this cost is relatively modest given the wide ranging potential benefits of civil registration and that the Global Fund to fight AIDS, Tuberculosis and Malaria spent US\$1.2 billion in 2008. Further, once established civil registration systems cost notably less to administer and maintain than the undertaking of population censuses and large household surveys, as after establishment civil registries are usually able to cover their operating costs using revenue collected from the issuance of official documents.<sup>4</sup>

## 2.7 Looking Ahead

Civil registration systems are essential - they underpin the legal tools to establish personhood and protect the civil rights of individuals, while also providing a high quality data source for the compilation of vital statistics. Given the wide ranging objectives that civil registration serves (ranging from rule of law, economic enterprise, population health to human welfare), the improvement of civil registration systems will require sustained commitment and collaboration between multiple sectors and across several administrative levels. For the demography, statistical and public health communities this is likely to require a shift in how we address the information gaps and measurement challenges in monitoring health and mortality in low-income countries. In short, there is a need to rediscover the centrality of civil registration in population health systems, and that other data sources are complements but not substitutes for high quality vital statistics derived from complete civil registration.

As the international community moves to assess progress towards the Millennium Development Goals and develop a post-2015 agenda as part of the International Conference on Population and Development, it is worth reflecting on Jong-Wook Lee's insightful comments during his tenure as Director-General of the World Health Organization: "To make people count, we first need to be able to count people" (Atlman, 2003). But we also need to recall that both institutions and measurement methods matter, and thus how we count has an effect on both the reliability

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<sup>4</sup>Civil registries do not charge individuals for the registration of vital events, but often collect nominal fees for the issuance of certificates (United Nations, 1998).

## 2.7. *LOOKING AHEAD*

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of our findings and the potential for instrumental contributions such population data systems can contribute to people's livelihoods.

## Chapter 3

# Consistency of Under-Five Mortality Rate Estimates Using Full Birth Histories and Summary Birth Histories

*This chapter has been published as Silva (2012).*

### 3.1 Introduction

In 2001, world leaders, recognizing the lack of progress in reducing under-five mortality and the need for more attention and resources to address the proximate determinants of under-five mortality, agreed to prioritize child mortality reduction as part of the United Nations Millennium Development Goals. In particular, the primary target of Millennium Development Goal 4 is for countries to reduce the level of under-five mortality by two-thirds of 1990 level by 2015.

The most reliable data source for estimating under-five mortality rate (the probability of dying between birth and age 5 years old, also denoted in the literature as  $U5MR$  and  ${}_5q_0$ ) at the national level is vital registration data, when such data are complete and timely. Yet, the countries where child mortality remains high or child mortality declines are slow or stagnant are those that lack comprehensive vital registration systems Mahapatra et al. (2007b). For these countries, analysts rely heavily on two common forms of retrospective birth history data: full and summary birth histories. In a full birth histories (FBHs), which are usually collected via a household survey, women are asked to retrospectively report each live birth, the date of the birth, and, if the child has died, its age at death. In summary birth histories (SBHs), which are mostly collected via a household survey or a population census, women are asked to report only summary information: the number of children ever born to them, the number of those children still surviving at the time of the survey,

and proxy exposure information (usually the mother's age, duration of her marriage, or time since her first birth). However, retrospective data in the form of both FBHs and SBHs suffer from a number of limitations Woodruff (2002). Hence, there are a number of challenging methodological issues in quantifying the magnitude and pattern of under-five mortality rates in many low- and middle-income countries. Analysts can derive direct estimates from FBHs, as they provide detailed information about the date of death and the exposure of children to the risk of dying Rutstein and Rojas (2006). In contrast, only indirect estimates are usually constructed from the summary information contained in SBHs, whereby such information as the mother's age are used as proxies for exposure to the risk of dying, to derive under-five mortality rate estimates using model life tables Brass (1964b); Brass et al. (1968); Brass (1971b); United Nations (1983). Of course, such indirect estimates can, and often are, also be derived from FBHs. The purpose of this paper is 2-fold. The first objective is, using available Demographic and Health Surveys (DHS) data, to provide guidance as to whether to use both direct and indirect analyses from FBHs. The second objective is to investigate whether analysts should use indirect estimates from SBHs at all. This analysis is intended to inform discussions about how to evaluate these two estimation methods and make inferences when the resulting estimates from direct and indirect estimation are inconsistent.

The accurate estimation of under-five mortality rates is important for two fundamental reasons. Firstly, the under-five mortality rate is an important indicator of population health Reidpath and Allotey (2003). It is widely used by the international agencies to monitor development progress as part of the Millennium Development Goals and other initiatives to improve population health and human welfare United Nations Children's Fund (2011). Secondly, the probability of dying before age 5-years old,  ${}_5q_0$ , is one of the principal input parameters used to develop estimates of life expectancy at birth and other summary indicators of mortality for developing countries without reliable vital registration Wilmoth et al. (2012). Thus, errors and biases in estimating child mortality lead to notable inaccuracies in other summary mortality measures.

The accurate estimation of under-five mortality rates is difficult in developing countries that lack comprehensive vital registration systems. In such cases, researchers have to rely on direct and indirect estimation methods applied to birth histories collected in ad-hoc retrospective surveys and population censuses. Such methods are vulnerable to data errors (inherent in retrospective data collection systems) and errors resulting from simplifying modelling assumptions. For example, one notable data error which can affect direct estimates constructed from FBHs is birth transference. This phenomenon involves the retrospective misreporting of the timing of children's birthdates which, if systematic across sampled birth histories, can lead to bias in estimates of under-five mortality rates. A key simplifying assumption of the Brass method is the assumption of constant fertility in the recent past - As the rate of fertility change in recent decades has varied substantially across populations from relatively small changes in West Africa to notable declines in Asia and Latin America.

## 3.2 Objectives

This paper aims to provide a systematic assessment of when direct and indirect methods result in different estimates, and how best to evaluate such inconsistencies. The paper seeks to provide a sounder empirical basis for the integration of data quality diagnostics into statistical curve fitting of point estimates. Such an integration is needed to ensure that the estimation process better accounts for bias and error in the underlying direct and indirect point estimates.

The primary methodological questions that are addressed in this paper include:

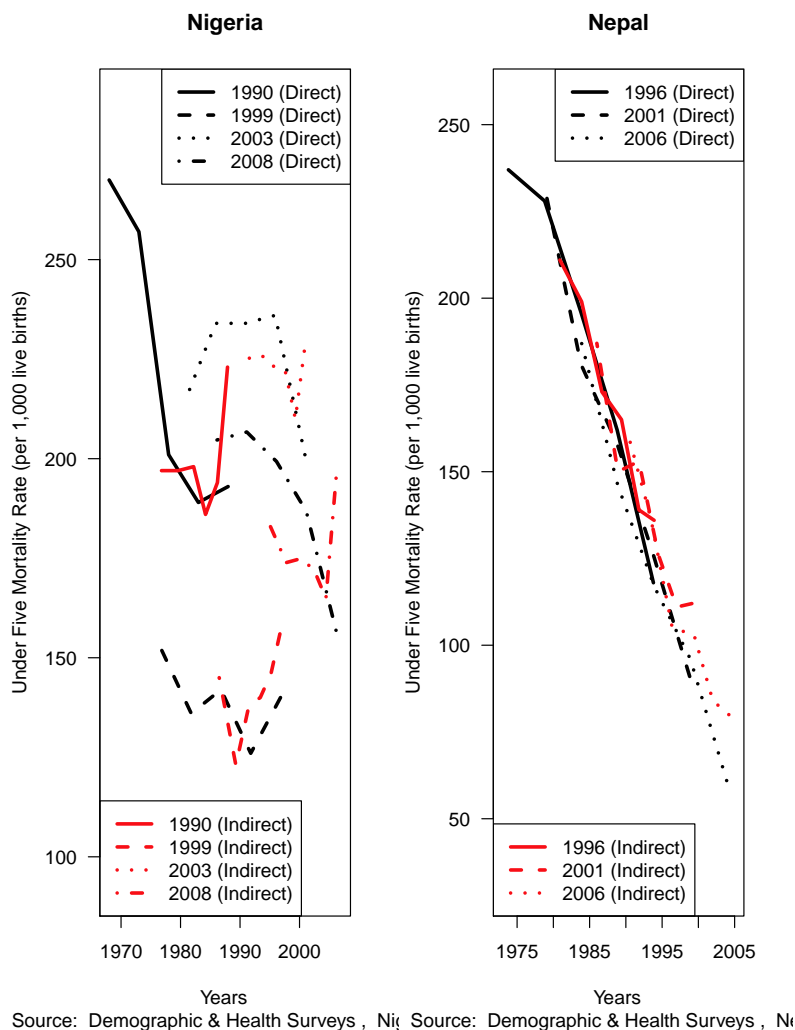
1. When full birth histories (FBHs) and summary birth histories (SBHs) are available from the same data source, should analysts use both the direct and indirect estimates from the same source in their analysis? If so, which form of the indirect method should be used?
2. under what (demographic) conditions direct estimation methods should not be used?
3. In contrast, under what conditions are indirect methods likely to provide more reliable and valid estimates of under-five mortality rates or sufficiently reliable estimates given the substantially lesser costs?

This comparative study represents a preliminary step towards integrating the early literature of data quality diagnostics and evaluation measures and recent efforts to combine multiple, defective under-five mortality estimates to aid inferential analysis of temporal trends. It assesses direct and indirect estimates by seeking to identify sources of systematic bias and random error in the different estimates. In particular, both potential sources of empirical data error/bias are examined as well as the errors and bias resulting from violations of underlying model assumptions.

## 3.3 Background & Motivation

There is considerable variation in the quantity and quality of DHS survey data for countries in the East African, West African, Latin American and South and Southeast Asian regions. To date, there has only been one DHS in Sierra Leone, whereas six separate DHS surveys in Senegal that have collected both full and summary birth histories. For illustrative purposes, Figure 3.1 displays the available DHS survey data on under-five mortality rates for Nepal and Nigeria. The direct and indirect estimates derived from Nepalese DHS data are fairly consistent. Whereas, summary and full birth histories from Nigerian DHS surveys yield highly inconsistent estimates. Such variation in quantity and quality of DHS birth history data poses considerable challenges when attempting to infer temporal patterns and trends in under-five mortality rates in the absence of high quality vital registration data.

Previous studies on the consistency of direct and indirect estimates of under-five mortality rates have mostly focused on select surveys from the WFS conducted in the 1970s and 1980s and a small



**Figure 3.1: Direct and Indirect Estimates of Under-Five Mortality Rates from available DHS survey data for Nigeria & Nepal.**

number of surveys from early waves of the Demographic & Health Survey program. These studies all identified measurable differences between direct and indirect estimates but were not unanimous in their conclusions. Both Preston (1985) and Adetunji (1996) attributed most of these differences to violations of the assumptions underlying the Brass indirect method Preston (1985); Adetunji (1996) . In contrast, the United Nations (1992) suggested that in some circumstances indirect methods may still provide useful evidence of levels and trends in under-five mortality rates United Nations (1992b). Given the increasingly importance of and reliance on Demographic & Health

Surveys for estimating under-five mortality in high mortality countries, this article examines the consistency

## 3.4 Overview of Estimation Methods

### Review of Full & Summary Birth History Methods

Direct estimation of under five mortality, using either an household survey or a population census, is derived from full birth histories of women between the ages of 15 and 49 years old.<sup>1</sup> In a full birth history, women are asked to report for each live birth, the date of the birth and, if the child has died, its age at death. With a full birth history, a synthetic cohort life table approach can be used which combines mortality probabilities for small age segments based on actual cohort experience into more common age groups (Rutstein and Rojas, 2006).

Indirect estimation of under five mortality rates requires, at the very least, abridged birth histories where women report the total number of children ever born to them and the number who are still alive at the time of the survey. This indirect estimation technique was initially outlined in Brass (1964b); Brass et al. (1968); Brass (1971b) and builds on the insight that the number of deaths at given age and the probability of dying in that age group is primarily determined by the age pattern of fertility. The original Brass method assumed that recent fertility and mortality levels were constant and a child's mortality risk was solely a function of his/her mother's age. Trussell (1975) subsequently extended the Brass method to allow for linear mortality decline, thus relaxing the strong constant mortality assumption in Brass's original model. Feeney (1980) further extended the Brass indirect estimation technique by developing a method to locate the estimates in calendar time prior to the survey date. Other authors sought to address potential biases resulting from misreporting by female respondents of their own age. Sullivan (1972) adapted the original Brass method so that information about children ever born and children surviving were organized around the woman's duration of marriage - implicitly assuming that marriage duration was subject to less reporting bias and was a reasonable proxy to model exposure years of the woman's children. Sullivan's variant of the Brass method, commonly referred to as the 'marriage duration' variant of the Brass method, is only applicable in populations where there is negligible fertility outside of marriages and formal unions. Hill and Figueroa (2001) developed the 'Time Since First Birth (TSFB)' variant of the Brass method in attempt to address age misreporting (particularly by elderly women). The TSFB method requires an additional question to be asked - namely about the year the female respondent experienced her first live birth.

The Brass method and its subsequent variants make adjustments to the proportion of children dead by the mother's age group (or by the mother's marital duration or by the time since first birth) for an estimated exposure distribution so as to estimate under-five mortality and associated

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<sup>1</sup>In Demographic & Health Surveys, birth histories are usually only collected from women between the ages of 15 and 49 years old. Further, in some cultures, sampled women are restricted to "ever married" women.

reference dates for these rates. The underlying adjustment process of the Brass indirect method is dependent on a number of key underlying assumptions (Brass et al., 1968; Brass, 1971b; Trussell, 1975). These include:

- no, or at worst a small, change in fertility levels and age patterns,
- either there is no change or a linear decline in mortality levels,
- the age-specific mortality pattern is consistent with model age patterns represented by the Coale-Demeny Model Life Table system or the United Nations Model Life Table system,
- mortality risks for the mother are independent of those for her child,
- mortality patterns for children are homogenous across all factors except the mother's age (or the time since the mother's first birth or the mother's duration of marriage).

The classical Brass method is an “indirect” method of estimation in that it (i) uses proxy information (in the form of either mother's age, time since first birth or mother's marriage duration) as a proxy for a child's exposure to mortality, and (ii) it first estimates general mortality measures, such as  $q(1)$ ,  $q(2)$ ,  $q(3)$ ,  $q(5)$ ,  $q(10)$ , and  $q(15)$  and then translates them to a common mortality measure such as  $q(5)$  (usually through the use of Coale-Demeny or United Nations Model Life Tables). The Rajaratnam low-cost method is a quasi-indirect method in that it uses indirect measures (of mother's age and/or time since first birth) to estimate a child's exposure to death, but directly estimates  ${}_5q_0$  from the proportion of deceased children,  $\frac{CD}{CEB}$ , using the logit transformation. This method was recently developed by researchers at the Institute of Health Metrics and Evaluation in attempt to improve and refine the classical Brass indirect estimation method. In this paper, we evaluate the Rajaratnam low-cost method alongside the classical Brass indirect method and direct estimation method (Rajaratnam et al., 2010b).

The Rajaratnam low-cost method was designed to address the following particular limitations of the classical Brass indirect estimation method:

- selection biases and small sample-size variability in summary birth histories collected from 15-19 and 20-24 year old women,
- the lack of a statistical framework associated with the classical Brass indirect method for the specification of uncertainty intervals around point estimates,
- a lack of external validation of indirect estimates, despite widespread application of the Brass indirect method over the last 50 years.

Further, the Rajaratnam low-cost method attempts to improve the use of proxy measures to approximate a child's exposure to the risk of death. Rajaratnam et al. (2010b) do this by (i) comparing the use of period-based and cohort-based measures of the proportion of children dead as



the key input to their model, and (ii) examining whether the mother's age or time since first birth provides better model fit. This method also specifies a combined method that synthesizes the four variants of period-based, cohort-based, age-based and time-since first birth methods using loess regression.

## **Analytical Strategy for Comparison of Full & Summary Birth History Methods**

The direct and indirect methods are theoretically supposed to result in unbiased estimates of infant/child mortality rates, despite the methods being based on two different forms of data and different model assumptions. The indirect method is particularly appropriate when infant/child mortality data are collected during a population census or when retrospective reporting of ages and dates are known to be unreliable. Recently, UNICEF has adopted the indirect method as its standard to measure infant/child mortality in least developed countries as part of the fourth phase of its Multiple Indicator Cluster Survey (MICS) program (UNICEF, 2009a). In adopting this method, UNICEF cited an "even greater need for up-to-date, high quality data to reflect the scaling-up of key maternal, newborn and child survival and health interventions and the related MDG indicators as we approach 2015," thus implying that abridged birth history information and the indirect estimation method may yield more valid and reliable results than the direct estimation method (UNICEF, 2009b).

This paper, in comparing direct estimation (using full birth histories) and indirect estimation methods (using summary birth histories), begins to explore the relative costs and benefits of the additional empirical information gained from full birth histories against the heavy reliance on model-based mortality patterns and simplifying mortality and fertility assumptions when using summary birth histories for indirect estimates. This analysis assumes that no estimation method is universally applicable in all situations, and thus attempts to identify under what circumstances is one method preferable to the other.

## **3.5 Literature Review**

### **Consistency of estimates from direct and indirect methods**

The literature on the consistency of the estimates derived from the two traditional methods of childhood mortality estimation is scanty. The few attempts made at checking the consistency of the methods are those by Preston (1985), Adetunji (1996) and the United Nations (1992b). Preston (1985) derived direct and indirect estimates of childhood mortality using world fertility survey (WFS) data collected in developing countries in the 1970s and the early 1980s and concluded that the estimates derived from the direct method provided more empirical evidence about trends in mortality and age patterns of mortality those from the indirect method. He noted that the full birth

histories are subject to recall errors that lead to erroneous dating of birth and death events, and identified systematic bias resulting from such dating errors through the analysis of age heaping (specifically around deaths at 12-months) and observation of erratic morality trends. However, he concluded that indirect estimates derived from summary birth histories are poor substitutes for direct estimates. Preston (1985) concluded that, based on data from the WFS, the lack of direct evidence of temporal trends and age patterns of mortality in summary birth histories leads to implausible estimates and potential systematic biases. He argued that, while both direct and indirect estimates are subject to bias, the systematic bias associated with indirect estimates are, on average, larger than those associated with direct estimates using full birth histories. In contrast to Preston (1985), Adetunji (1996) did not prefer one method to the other. Rather, he compared levels of infant mortality rates (IMR) derived from the two methods using DHS data from a small collection of African countries gathered in the 1980s and 1990s. He derived direct and indirect estimates of IMR from the data and compared the estimates using *t*-tests. He concluded that the direct and indirect methods gave estimates which were statistically different and that the differences were not entirely explained by errors in the data. He suggested that the differences could be due to intrinsic properties of the methods, thus causing notable challenges when attempts are made to combine estimates from the different methods to infer an overall pattern or trend. However, Adetunji (1996) did not explore the potential explanations for inconsistency between the two methods in detail.

The United Nations (1992b) also considered the consistency of the estimates from the two methods of childhood mortality measurement. It was concluded that there is no one method that works well in all situations, thus the need for using the direct method in some situations (for example, when the respondents are literate and are likely to give accurate dates of vital events) and to use the indirect method in situations where the available data for childhood mortality estimation are limited to just totals of children ever born and children surviving.

### **Inferring Under Five Mortality Rate Patterns from a Combination of Direct and Indirect estimates'**

When different data sources and methods of estimation are used, estimates of child mortality for a particular reference period tend to differ because of both sampling and non-sampling errors. They may also be dependent on the choice of methods as well as on violations of methodological assumptions. The magnitude of the differences increases with the degree of variation in the data sources and methods of analysis. This makes it difficult to analyse trends in under-five mortality rates. There have been four major efforts in combining multiple data sources on infant/child mortality, namely:

- graphical methods that rely on visual inspection and ad-hoc techniques (United Nations, 1992b),
- spline-based fitting methods (Hill et al., 1999),

- loess regression methods (Murray et al., 2007), and
- gaussian process regression.(Rajaratnam et al., 2010a).

These recent advances by the United Nations (1992b), Hill et al. (1999), and Murray et al. (2007) have advanced our understanding and statistical toolkit on how to combine multiple observations of infant/child mortality from different data sources. However, this recent literature fits smooth curves to the available observations, based on a coarse evaluation of data quality using methods that do not fully encapsulate the uncertainty of the available observations. The early methods, such as graphical fitting methods, splines and loess regression, focused exclusively on adapting available regression-based methods to the given data without attempting to identify, measure and incorporate data quality issues related to the underlying observations into the modelling exercise. Thus these early modeling exercises focused exclusively on adapting available regression-based methods to the given data without attempting to identify, measure and incorporate data quality issues related to the underlying observations into the modelling exercise. There is a body of literature on how to identify and measure data quality issues for infant/child mortality data collected from sample surveys and population censuses. For example, Sullivan et al. (1994b) noted that under five mortality data from the DHS survey program were vulnerable to several biases and errors, such as problems encountered in the reporting of information on dead children, the phenomena that mothers were considerably less able to remember the date of birth of children who had died, and evidence in over half the surveys of a displacement of births of dead children from the 5th to the 6th calendar year prior to the survey. Pullum and Sullivan (2008) assessed whether there is differential birth displacement according to survivorship status, and explored procedures to correct for any resulting bias in estimated mortality rates.

## 3.6 Methods

### Data

The empirical analysis of this paper is focused on the examination of relative differences between direct and indirect estimates of under-five mortality rates. Direct and indirect estimates are derived from DHS data collected in West Africa, East Africa, South and Southeast Asia and Latin America. Table 3.1 lists the data sources used in this analysis.

### Tables

Table 3.1: **Data Sources Used to Examine Consistency of Direct and Indirect Under-five Mortality Rate Estimates from a Common Data Source.**

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<b>No.</b>	<b>Country</b>	<b>DHS Survey(s)</b>
1	Bangladesh	1993, 1996, 1999, 2004, 2007
2	Burkina Faso	1992, 1998, 2003
3	Benin	1996, 2001, 2006
4	Bolivia	1989, 1993, 1998, 2003, 2008
5	Brazil	1986, 1991, 1996
6	Burundi	1987
7	Congo, DRC	2007
8	Central African Republic	1994
9	Congo Brazaville	2005
10	Cote d'Ivoire	1994, 1998
11	Cameroon	1991, 1998, 2004
12	Colombia	1986, 1990, 1995, 2000, 2004, 2009
13	Dominican Republic	1986, 1991, 1996, 1999, 2002, 2007
14	Ecuador	1987
15	El Salvador	1985
16	Ethiopia	1985, 1992, 1997
17	Ghana	1988, 1993, 1998, 2003, 2008
18	Guinea	1999, 2005
19	Guatemala	1987, 1995
20	Guyana	2005, 2009
21	Honduras	2005
22	Haiti	1994, 2000, 2005
23	Indonesia	1992, 2005
24	India	1987, 1991, 1994, 1997, 2007
25	Kenya	1988, 1993, 1998, 2003, 2008
26	Cambodia	2000, 2005, 2010
27	Liberia	1986, 2006
28	Sri Lanka	1987
29	Mali	1987, 1995, 2001, 2006
30	Malawi	1992, 2000, 2004
31	Mexico	1987
32	Nicaragua	1997, 2001
33	Nigeria	1990, 1999, 2003, 2008
34	Niger	1992, 1998, 2006
35	Nepal	1996, 2001, 2006
36	Peru	1986, 1991, 1996, 2000
37	Philippines	1993, 1998, 2003, 2008
38	Pakistan	1990, 2006

39	Paraguay	1990
40	Rwanda	1992, 2000, 2005
42	Sierra Leone	2008
43	Senegal	1986, 1992, 1997, 2008
44	Chad	1996, 2004
45	Togo	1988, 1998
46	Thailand	1987
47	Tanzania	1991, 1996, 1999, 2004, 2009
48	Uganda	1988, 1995, 2000, 2006
49	Vietnam	1997, 2002

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**Table 3.1 Source: Demographic & Health Surveys, 1985-2009**

## Methods of Analysis

These differences are evaluated and then successively re-analyzed after diagnostic analysis of and adjustment for various shortcomings of the classical direct and indirect estimation methods. In particular, I successively carried out diagnostic analysis and re-estimation of rates to account for birth omissions and birth transference in full birth histories used in direct estimation. I also adjusted indirect estimates by relaxing the implicit constant fertility assumption that underlies the classical Brass indirect method. After each readjustment of the estimates, I successively reviewed the paired differences between the direct and indirect estimates. In order to characterize the observed differences, after controlling for potential data errors in the full birth histories and adjusting for violations of assumptions that underly the Brass method, I drew on categorizations developed by Garenne & Gakusi (2006) Garenne and Gakusi (2006). In particular, I classified the inconsistencies between revised direct and indirect estimates according to the nature of health and mortality transitions. These classifications distinguish countries by their apparent health transition experience between 1950 and 2000, estimated using pooled direct estimates when several surveys were available for a given country. The classifications organize countries into five main categories: those that experienced (i) a smooth monotonic mortality decline, (ii) minor mortality increases over short periods of time, (iii) major mortality increases due to political and economic crises, (iv) stalled mortality declines for several years, and (v) recent mortality increases due to infectious disease outbreaks. These classifications provide a useful framework to identify the magnitude of observed differences in direct and indirect estimates, relative to the type of health and mortality transition experienced. This helps to identify different inconsistencies observed across different health transitions, particularly when there is deviation from linear mortality decline in the recent past.

I examined the mean relative differences between under-five mortality rate estimates derived using the direct estimation method and the indirect estimation method. Direct estimates were calculated using the synthetic cohort method. The indirect estimates are calculated using two different indirect methods: the classical Trussell version of the Brass Indirect Method and an adjusted version of the Trussell version that uses cohort-specific parities to relax the constant fertility assumption.

I used paired difference tests to examine whether the indirect estimates were measurably different from corresponding direct estimates. Direct estimates were re-estimated for calendar years corresponding to indirect estimates (associated with SBHs obtained from women aged 25-29, 30-34, and 35-39 years old). The calendar years for indirect estimates were derived using the standard method for time-referencing of indirect estimates Feeney (1980).

The relative difference between these two estimation methods by  $d_i$  was defined as follows:

$$d_i = \frac{\hat{x}_{i,indirect} - \hat{x}_{i,direct}}{\frac{1}{2}(\hat{x}_{i,indirect} + \hat{x}_{i,direct})} \quad (3.1)$$

where  $\hat{x}_{i,indirect}$  and  $\hat{x}_{i,direct}$  are the estimated rates derived from indirect method and direct method, respectively, for the  $i^{th}$  year prior to the survey.

I formulated the following hypothesis test to examine whether the mean relative difference between the two estimates is measurably different from zero:

$$H_0 : \mu_d = 0 \quad (3.2)$$

$$H_A : \mu_d \neq 0 \quad (3.3)$$

My analysis was focused on differences associated with estimates derived from birth histories of women aged between 25-29, 30-34, and 35-39 years old. I excluded the summary birth histories from 15-19 and 20-24 year old women, since the indirect estimates associated with these age groups are subject to notable selection bias and imprecision. This is consistent with the standard methodology used by the United Nations Inter-Agency Group on Mortality Estimation UNICEF, WHO, The World Bank and UN Population Division (2007). The selection bias results from the over-representation of births to women of low socioeconomic status in this age group, whereas imprecision results from the notably smaller sample sizes of these birth cohorts. Estimates based on birth histories collected from older women are excluded due to their vulnerability to notable levels of recall error Pullum and Stokes (1997). I expected any observed difference to, on average, be explained by reliance on model-based age patterns when using the indirect estimation method and additional data errors and biases to which full birth histories may be vulnerable. To accurately compare direct and indirect estimates, direct estimates were centered on the time-references associated with the comparable indirect estimates.

## 3.7 Results

Table 3.2 displays the results of the paired difference tests using DHS birth histories from West Africa, East Africa, Latin America, and South & Southeast Asia. This analysis is based on DHS data from 132 surveys in 49 countries, as described in Table 3.1. Surveys from Southern Africa were excluded as such data were likely to be affected by survivorship biases resulting from high HIV prevalence. Data from Australasia was excluded, as it only includes Tonga. Data from Europe and Central Asia were excluded, since most of those countries have attained under-five mortality rate levels below 35 per 1,000. Relative paired differences are reported for mortality estimates associated with summary birth histories from women aged 25-29, 30-34 and 35-39 years old. We observe that the differences are uniformly positive across all regions, and individually statistically significant. This is broadly consistent with earlier comparisons which found that, using fifteen birth histories collected as part of the World Fertility Survey program, the Brass indirect estimation method resulted in infant mortality rate estimates that were, on average, 20-35% higher than those derived using the same data source but by employing the direct estimation method Adetunji (1996). This earlier analysis focused on the following fifteen countries: Botswana, Zimbabwe, Namibia, Kenya, Senegal, Burkina Faso, Ghana, Nigeria, Tanzania, Uganda, Zambia, Malawi and Liberia. These findings suggest that when analysts combine estimates from summary and full birth histories, they need to factor in such differences to ensure that temporal patterns aren't inferred from error or bias resulting from a particular estimation method.

The paired relative differences for Latin America and Asia tend to be larger than those for West and East Africa. This is likely a result of bias in the Brass indirect method due to violation of the assumption of constant fertility in the recent past, given the, on average, larger fertility declines experienced in Asia and Latin America.

So the critical questions for investigation are

- are these differences driven by potential data errors in the DHS survey data for West Africa, East Africa, Latin America and South/Southeast Asia? or
- do these differences result more from some of the key assumptions of the Brass indirect method being violated for the populations being studied?, or
- do they appear to be a combination of data errors and underlying methodological assumptions being violated?

The remaining parts of this section investigate whether these observed differences can be explained by apparent data quality issues with the DHS survey data from these regions. I also discuss how much of these differences are attributable to the implausibility of the Brass indirect method assumptions.

## Diagnostic Analysis of Potential Errors & Biases in Direct and Indirect Estimates

### Decomposition of Brass Indirect Estimator into Error Components

The Brass indirect estimation method can be decomposed into a first component that is affected by model-based errors and a second component that is affected by data errors in the summary birth histories. This formal decomposition, which is presented in this section, is a helpful way of identifying and classifying components of variability in the Brass indirect estimation method.

The Brass indirect estimation method is used to estimate the probability of dying before a given age,  $M$ , denoted as  $q(M)$  in the following way:

$$\hat{q}(M) = k \cdot D_x \quad (3.4)$$

where  $D_x$  is the proportion of dead children born to mothers of a given age,  $x$ , and  $k$  is an estimated constant used to transform the observed data on  $D_x$  to  $q(M)$ .

The proportion of deceased children can be written in the following way:

$$D_x = \int_0^{x-\alpha} c_x(a)q(a)da \quad (3.5)$$

where  $c_x(a)$  is the relative frequency of children at age  $a$  for women aged  $x$  and  $q(a)$  is the probability of dying between birth and age  $a$  in the reference population. In reality, as we cannot measure  $D_x$  exactly, we estimate it using survey data (like those collected in a DHS) as follows:

$$D_x \approx \int c_{x,s}(a)q_s(a)da \quad (3.6)$$

where  $c_{x,s}(a)$  is the relative frequency of children at age  $a$  in the survey population and  $q_s(a)$  is the probability of dying between birth and age  $a$  in the survey population.

The conversion constant,  $k$ , used to transform the proportion of deceased children into the mortality statistics  $q(x)$  can be written as:

$$k = \frac{q_M(M)}{\int c_{x,M}(a)q_M(a)da} \quad (3.7)$$

where  $c_{x,s}(a)$  is the relative frequency of children at age  $a$  and  $q_s(a)$  is the probability of dying between birth and age  $a$  as per a particular set of fertility and mortality model specifications.

By combining equations 3.6 and 3.7, we can rewrite the Brass indirect estimation equation as follows:



$$\hat{q}(M) \approx \frac{\overbrace{q_M(M)}^{\text{Model-Based}}}{\int c_{x,M}(a)q_M(a)da} \underbrace{\int c_{x,s}(a)q_s(a)da}_{\text{Survey-Based}} \quad (3.8)$$

This representation of the Brass indirect estimation method, shown in Equation 3.8, helps us to explicitly identify which parts of the estimator is subject to model uncertainty and which parts of the estimator are vulnerable to data errors and biases. Specifically, that model-based error and bias is generated from the component  $D_x \approx \int c_{x,s}(a)q_s(a)da$  and survey-based error results from the component  $k = \frac{q_M(M)}{\int c_{x,M}(a)q_M(a)da}$ .

If the model parameters and data are error-free, then the estimate is correct such that

$$\hat{q}(M) = q(M) \quad (3.9)$$

$$= \frac{q(M)}{\int c_x(a)q(a)da} D_x \quad (3.10)$$

### Data Errors in Birth Histories

It is difficult to identify and assess data errors in indirect estimates, in the absence of a gold standard (eg vital registration data). Yet, there are a number of potential data errors that can affect summary birth histories. Omissions of live births from birth histories are a possible area for indirect estimates to be vulnerable to systematic bias, as the nature of a summary birth history does not force a mother to recall each live birth individually. However, large survey programs like the DHS and MICS often entail a level of probing and question customization (usually by including questions about children who no longer live with the mother) to minimize such omissions.

In examining summary birth histories, I focused on evaluations of the recorded female age distribution, sex ratio at birth and parity distribution. When examining the available data for 49 countries from DHS surveys, I found that data generally conformed to the expected patterns of data quality diagnostics. In general, diagnostic analysis of summary birth histories did not identify serious flaws in the available data aside from anomalies in sex ratio data in South Asia and some anomalies in female age distributions in conflict-affected countries.

### Potential Data Errors and Biases in Direct Estimates

Demographic and Health Surveys contain two questionnaire modules in which data are collected on antenatal, delivery, and postnatal care of the mother for recent births and on numerous health and nutrition issues for these children. These modules of the questionnaire must be administered for each birth which occurs after a pre-defined cut-off date, typically set to January of the fifth complete calendar year prior to a survey (but for some surveys in DHS Phase III set to January

of the third calendar year prior to the survey).

For all births occurring subsequent to the pre-defined cut-off date, the DHS contains approximately 100 additional questions on maternal and child health. Field staff in DHS surveys can considerably lessen their workload by recording births that actually occur after the cut-off date as occurring before that date and, in turn, avoiding the administration of additional survey modules that apply to child births occurring before the cut-off date. Some analysts have documented such birth transference in DHS surveys Pullum and Sullivan (2008). Such birth transference can affect mortality rates if it happens in a frequent and systematic fashion and particularly if it affects dead and alive children differently.

Possible displacement of births beyond the reference date in the maternal and child health sections can be discerned by tabulating a birth concentration index, as follows:

$$\text{Birth Concentration Index} = 100 \times \frac{2 \times B_t}{(B_{t-1} + B_{t+1})} \quad (3.11)$$

where  $B_{t-1}$ ,  $B_t$ , and  $B_{t+1}$  are the number of births in the  $t - 1$ ,  $t$  and  $t + 1$  calendar years.

This index should be close to 100. A value of less than one hundred implies fewer births than expected for year  $t$ .

The birth concentration index is calculated where (i)  $t$  is the last year for which a child is eligible and again (ii) when  $t$  is the year prior to the last year of eligibility for the maternal and child health sections. The last year of eligibility for these sections is defined to be the fifth year preceding the survey for most DHS surveys, and the third year for a few surveys (usually carried out in DHS Phase III).

Figure 3.2 displays a box plot of the displacement ratios for births to surviving and dead children across different phases of the DHS for surveys listed in Table 3.1. We observe that there is a notably higher concentration of births documented for children who died than those who survived. Also, the extent of birth transference appears to have increased in Phases IV & V of the DHS, relative to earlier phases of the DHS.

For estimates pertaining to the 5-year period immediately before the survey, such birth transference is likely to cause a systematic downward bias in under five mortality rate estimates. Whereas, for estimates pertaining to the penultimate 5-year period, it is likely to result in a systematic upward bias.

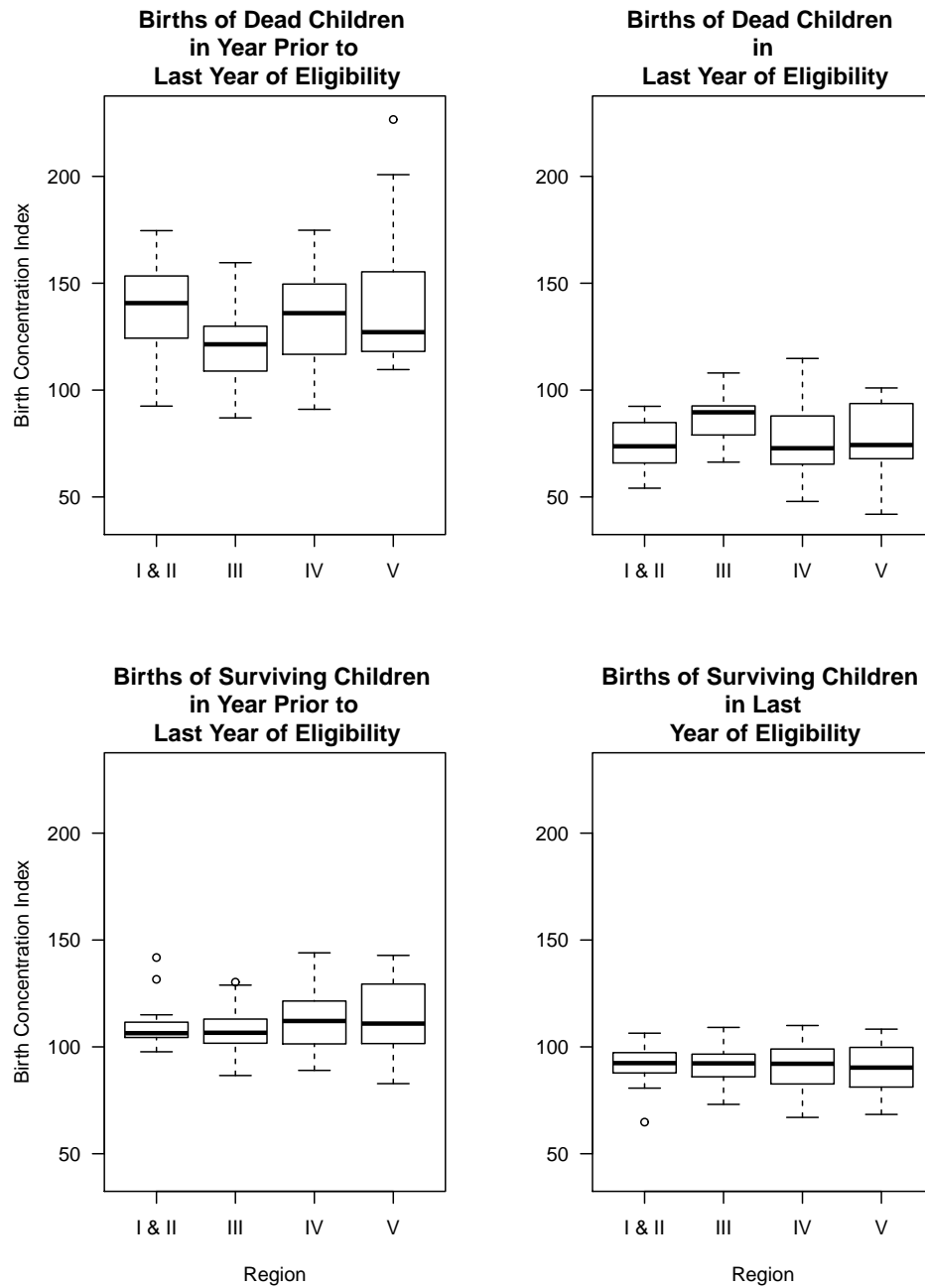


Figure 3.2: Documented Birth Transference by DHS Phase for Births of Surviving and Dead Children in Last Year of Eligibility and in Year Prior to Last Year of Eligibility.

### Adjustment of Direct and Indirect Estimates for Possible Data Errors

I investigated whether the effect of data errors in full birth histories and the main assumptions of the Brass indirect method explain the differences between direct and indirect estimates observed in Table 3.2. I did this by successively examining paired differences after adjusting for data errors in full birth histories and then some of the main assumptions of the Brass indirect method. I adjust for birth transference by re-estimating the direct estimates for the time period that immediately precedes January of the year prior to health cutoff for the given birth history. These re-estimated rates capture births (and deaths) that have been transferred across the health module cut-off date. The expected effect of this re-estimation is an increase in the mortality rate for the estimation period immediately preceding the survey and a decrease in the rate for the penultimate estimation period.

Table 3.2: **Relative Paired Differences (reported at percentages) between Direct and Indirect Estimates across Geographic Regions Derived Using Demographic & Health Surveys**

	Age Group	Mean Rel. Difference	95% CI
Asia	25-29	9.99	(2.2, 17.8)
	30-34	19.5	(12.5, 26.5)
	35-39	35.0	(26.9, 43.1)
Latin America	25-29	12.7	(7.5, 17.9)
	30-34	23.0	(16.7, 29.4)
	35-39	38.9	(34.3, 43.6)
East Africa	25-29	11.7	(7.6, 15.8)
	30-34	6.9	(1.9, 11.9)
	35-39	10.1	(5.2, 15.1)
West Africa	25-29	6.7	(1.7, 11.6)
	30-34	9.2	(3.3, 15.5)
	35-39	13.7	(8.7, 18.7)
All Regions	25-29	11.5	(8.7, 14.1)
	30-34	17.2	(14.1, 20.3)
	35-39	29.0	(25.9, 32.0)

I adjusted for potential violations of the constant fertility assumption of the Brass method by recalculating the Brass indirect estimates by using cohort-specific parities available in the full birth history of the DHS. By using cohort-specific parities instead of the aggregated period parities, I

adjusted for changes in fertility over time instead of assuming constant fertility in the recent past as is the case in the Trussell version of the Brass method.

Figure 3.3 displays the results of a series of successive paired difference tests between direct and indirect estimates calculated from 132 DHS surveys in 49 countries for the age groups 25-29, 30-34 and 25-39 years old. The DHS survey data sources used in this analysis are listed in Table 3.1. Across the three age groups (25-29, 30-34, and 35-39 years old) and the four geographic regions, successive adjustment for birth transference and violations of the constant fertility assumption of the Trussell version of the Brass method resulted in increased consistency between direct and indirect estimates, as shown in Figure 3.3. This result is consistent with the hypothesis that most of the difference between direct and indirect estimates derived from the same DHS birth histories is explained by birth transference and violations of the constant fertility assumption of the Brass indirect method. For Asia, Latin America, and West Africa, adjustment of both direct and indirect estimates (to control for the effects of birth transference and relax the assumption of constant fertility in the recent past, respectively) results in notably more consistent estimates. However, this is not the case for estimates associated with the East African region. For this region, adjustment only of one set of estimates improves consistency. But adjustment of both direct and indirect methods results in estimates that are less consistent than when neither estimate is adjusted. Further, for this region, in contrast to others, adjusted indirect estimates tend to be approximately 10%-20% lower than adjusted direct estimates. Recent literature has noted that identifying fertility trends in several sub-Saharan African countries, particularly East African countries, is challenging and that there are several inconsistent findings amongst recent studies that all rely on DHS data Machiyama (2010). Depending on the fertility estimation method used, some researchers find a fertility stall where others identify a fertility decline Bongaarts (2006, 2008); Schoumaker (2009); Garenne (2008); Westoff and Cross (2006); Sneeringer (2009); Machiyama (2010). Machiyama (2010) concluded that these inconsistencies are a function of DHS data being vulnerable to age displacement of children, omission, and other survey errors. Thus, for countries where recent fertility decline is small or nonexistent, the cohort-based parity adjustments may over-adjust the indirect estimates.

Across the three age groups (25-29, 30-34 and 35-39 years) and the four geographic regions, successive adjustment for birth transference and violations of the constant fertility assumption of the Trussell version of the Brass method resulted in increased consistency between direct and indirect estimates, as shown in Figure 3.3. This result is consistent with the hypothesis that most of the difference between direct and indirect estimates derived from the same DHS birth history is explained by birth transference and violations of the constant fertility assumption of the Brass indirect method. For Asia, Latin America, and West Africa adjustment of both direct and indirect estimates (to control for the effects of birth transference and relax the assumption of constant fertility in the recent past, respectively), results in notably more consistent estimates. However, this is not the case for estimates associated with the East African region. For this region, adjustment only

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### **Detailed Examination of Consistency Between Direct and Indirect Estimates Across Different Health Transition Typologies**

By decomposing health and mortality transitions into these different typologies, Garenne & Gakusi (2006) are able to identify the key underlying factors that drive variation in health transitions in sub-Saharan Africa Garenne and Gakusi (2006). I use their typological framework and extend it to countries in South/Southeast Asia and Latin America. Given the Brass indirect estimation method's assumption of constant fertility in the recent past, this framework is useful to assess the potential impact of violations of the constant mortality assumption of the Brass method on consistency of direct and indirect estimates (after controlling for birth transference and fertility change, respectively). Figure 3.4 displays the paired relative differences between direct and indirect estimates for countries organized by these typological categories. For countries that experienced a steady mortality decline (labeled "SMD"), the paired relative differences between the direct and indirect estimates associated with birth histories from women aged 25-29, 30-34 and 35-39 years old are relatively large, when raw direct and indirect estimates are considered. However, these differences are substantially reduced (approximating zero for birth histories from women aged 25-29 and 30-34 years old), after adjusting for birth transference in direct estimates and violations of the Brass method assumptions. This suggests that for populations that have experienced a steady mortality decline, there is very little difference in using direct and indirect estimates derived from birth histories from women aged 25-29, 30-34, and 35-39 years old once appropriate adjustments are made for data errors and violation of the Brass method assumptions. In contrast, for countries that experienced political and economic crises, periods of excess mortality and periods of stagnation (labelled "PEC," "XSM," and "STA."), notable differences remained between direct and indirect estimates even after controlling for data errors in the direct estimates and assumption violations in the Brass indirect method. This result suggests the need to explore these cases in more detail, as presented in the following paragraphs.

As the Trussell version of the Brass indirect method assumes linear mortality change in recent

times, the violation of this assumption is one potential source of inconsistency between direct and indirect estimates. Figure 3.5 presents example cases showing the consistency of the two types of estimates across different health transition characterizations, after adjustments are made for birth transference (in direct estimates) and fertility change (in indirect estimates) by using cohort-specific parity ratios. Point estimates derived using both direct and indirect estimation methods are shown in each graph. In addition, three loess curves are fitted for each country: one through the direct estimates only, one through the indirect estimates only and one through the full combination of direct and indirect estimates.

For countries that experienced either smooth mortality declines or short periods of excess mortality, such as Malawi and Tanzania in Figure 3.5, there is little observable difference between general fitted trends using only direct estimates, only indirect estimates or a combination of the two. However, in the case of populations that experience periods of excess mortality, the indirect estimates do a poor job of capturing short-term patterns (as seen for Tanzania in the early 1980s). For Niger, a population that experienced a stall in mortality decline through the 1970s, 1980s and early 1990s, direct estimates capture a general trend of stagnation followed by decline. On the other hand, the indirect estimates are more variable during the period of stagnation, suggesting more variation than their direct counterparts in 1980s and 1990s, and suggest the onset of mortality decline began only in the mid 1990s. However, after the onset of mortality decline in Niger, both the direct and indirect estimates are generally consistent.

For Rwanda, a country that experienced a political/economic crisis in the form of the 1994 genocide, the adjusted direct and indirect estimates have notable inconsistencies both before and after the elevated mortality period around 1994. The indirect estimates tend to smooth out rapid change in mortality, and therefore underestimate both the effect of the 1994 genocide. Further, the mortality peak is dislocated in time (to before the actual genocide), suggesting that in such crisis situations indirect estimates are particularly vulnerable to time-location errors and bias. Further as Pedersen (2012) has noted, when examining acute mortality crises such as the Rwandan genocide under-five mortality rates that were estimated using 5-year periods tended to smooth out the genocide-related mortality unlike when 1-year periods are used Pedersen (2012).

## 3.8 Discussion

This chapter has examined the consistency of direct and indirect methods used to estimate under-five mortality rates when high quality vital registration data are not available. Assessments were made of direct and indirect estimates derived from a common full birth history (such as a Demographic & Health Survey). Specific examination of the relative effects of data errors in full birth histories (principally birth transference) and violations of simplifying assumptions in the summary birth history methods (principally assumptions about fertility and mortality patterns in the recent

past) was undertaken.

The main finding from this research is that indirect estimates are generally consistent with direct estimates, once adjustment is made for fertility change and birth transference, but don't appear to add much additional insight beyond direct estimates. However, choice of method does matter both in the indirect method used and in adjusting for data errors and the constant fertility assumption of the Brass indirect approach. This study strengthens the existing literature on comparisons of direct and indirect estimation of under-five mortality, by drawing on a larger body of empirical data than previous studies and by also successively adjusting estimates for identifiable errors and biases.

When examining relative differences across different health and mortality transitions, greater inconsistencies between direct and indirect estimates were observed for countries that had experienced either a political or economic crisis or a stalled health transition. In contrast, in countries where either smooth mortality declines or only short periods of excess mortality were experienced, the adjusted estimates were generally consistent. These findings suggest the importance of adjustment for birth transference and use of cohort parity data when constructing direct and indirect estimates from FBHs. They also suggest the general consistency of the Brass indirect method during relatively smooth health transitions, but point to its limitations when applied to crisis mortality situations or populations that have experienced stalled health transitions.

The analysis presented here suggests that, when FBHs are available, adjusted indirect estimates are generally consistent with the comparable direct estimates. The basis for adjustment to such indirect estimates is the use of cohort-specific parities from the FBHs, as opposed to the period parities used in the classical Brass method. The clearest inconsistencies between the two estimates are observed in populations whose recent health transitions have departed substantially from a smooth mortality decline. These findings suggest that such indirect methods can be useful but are unlikely to provide deeper insights and more reliable estimates than direct methods, when FBHs are available. This finding lends support to, when FBHs are available, reliance on direct estimates from the FBHs when trying to infer the overall pattern of under-five mortality change over time. However, in the special case when birth transference in FBHs is considerable and both mortality and fertility in the recent past have been approximately constant, indirect estimates may be preferable.

### **3.9 Future Research Directions**

This chapter has examined the consistency of direct and indirect estimates from widely-available survey data. Retrospective full birth histories and summary birth histories are implemented in situations where comprehensive vital registration system is unavailable. As a result, this analysis,



like previous empirical investigations into direct and indirect estimates of under-five mortality estimates, is limited by the lack of ground truth data against which summary and full birth history methods could be validated. As a result, this study has focused on consistency between different estimates, as opposed to the validity of the underlying estimates themselves. That being said, there are two natural extensions to this study that are likely to lead to new insights into the remaining questions about the validity and reliability of direct and indirect estimates collected through ad-hoc surveys and population censuses.

First, the Demographic Surveillance Sites (DSS) coordinated by the INDEPTH Network collect high-quality vital registration information in a diverse set of developing country subnational populations. By carrying out a series of retrospective mortality surveys, in which a summary birth history is included, researchers could study both the reliability and validity of the summary birth history methods. Essentially, the DSS fertility and mortality registration data could be treated as ‘ground truth’ data. Such a series of studies are likely to lead to new insights into the real-world performance of full and summary birth history methods in different demographic and epidemiological settings.

Second, demographic microsimulation can be used to more explicitly explore some of the main assumptions of the indirect estimation methods. Specifically, through such a simulation testbed framework, the types and magnitudes of error and bias associated with permutations and combinations of data errors and model assumption violations could be examined. Such an examination would be useful to better understand the variability due to model misspecification and data errors associated with estimates derived from summary birth histories.

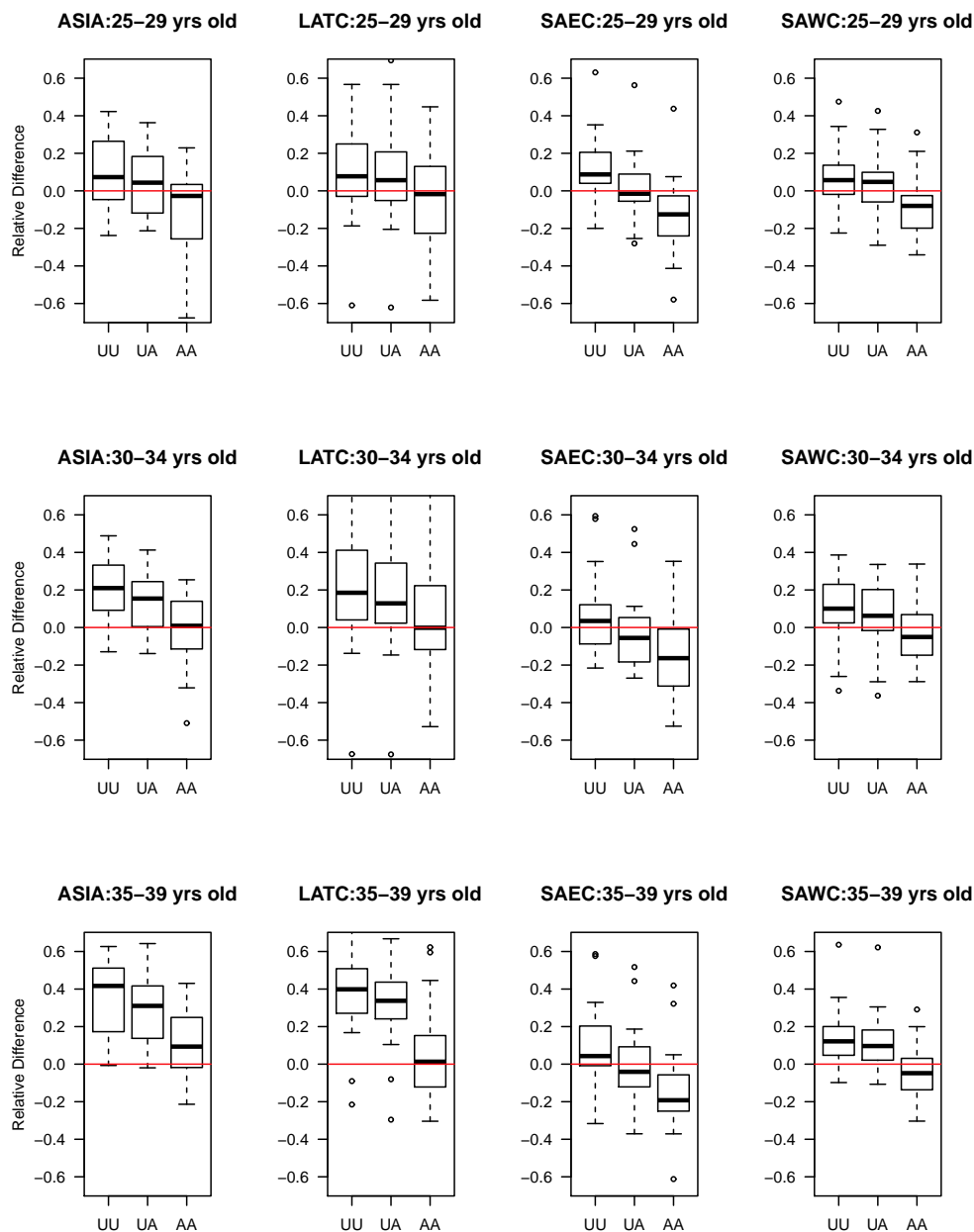


Figure 3.3: **Relative Paired Differences between Under-Five Mortality Rate Estimates derived from Demographic & Health Surveys by Age Group of Mother & Geographic Region.** Regions include South and Southeast Asia (“ASIA”), Latin America & the Carribean (“LATC”), East & Central Africa (“SAEC”), and West Africa (“SAWC”). In each panel, the left box plot displays the relative paired difference between raw direct estimates and classical Brass indirect estimates (UU); the middle box plot displays the relative paired difference between direct estimates that have been adjusted for birth transference and classical Brass indirect estimates (UA); and the right box plot displays the relative paired difference between direct estimates after adjustment for birth transference and cohort-parity-based Brass estimates (AA). Source: Demographic & Health Surveys, 1985-2009.

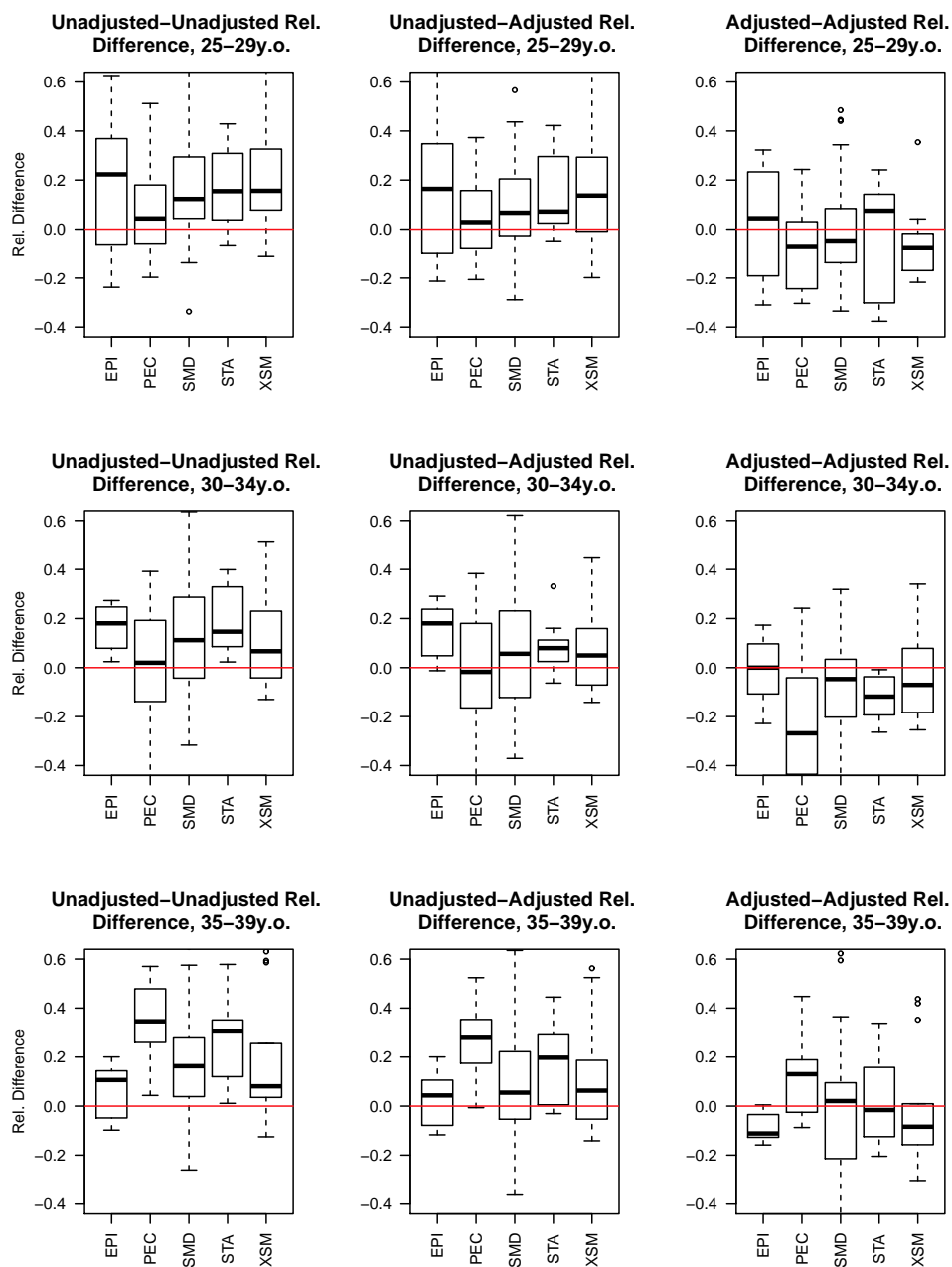


Figure 3.4: Estimated Relative Paired Differences for Under-Five Mortality Rates for developing countries organized by Garenne & Gakusi (2006) categories - Epidemic Crisis (EPI), Political & Economic Crisis (PEC), Smooth Mortality Decline (SMD), Periods of Stagnation (STA), and Periods of Excess Mortality (XSM).

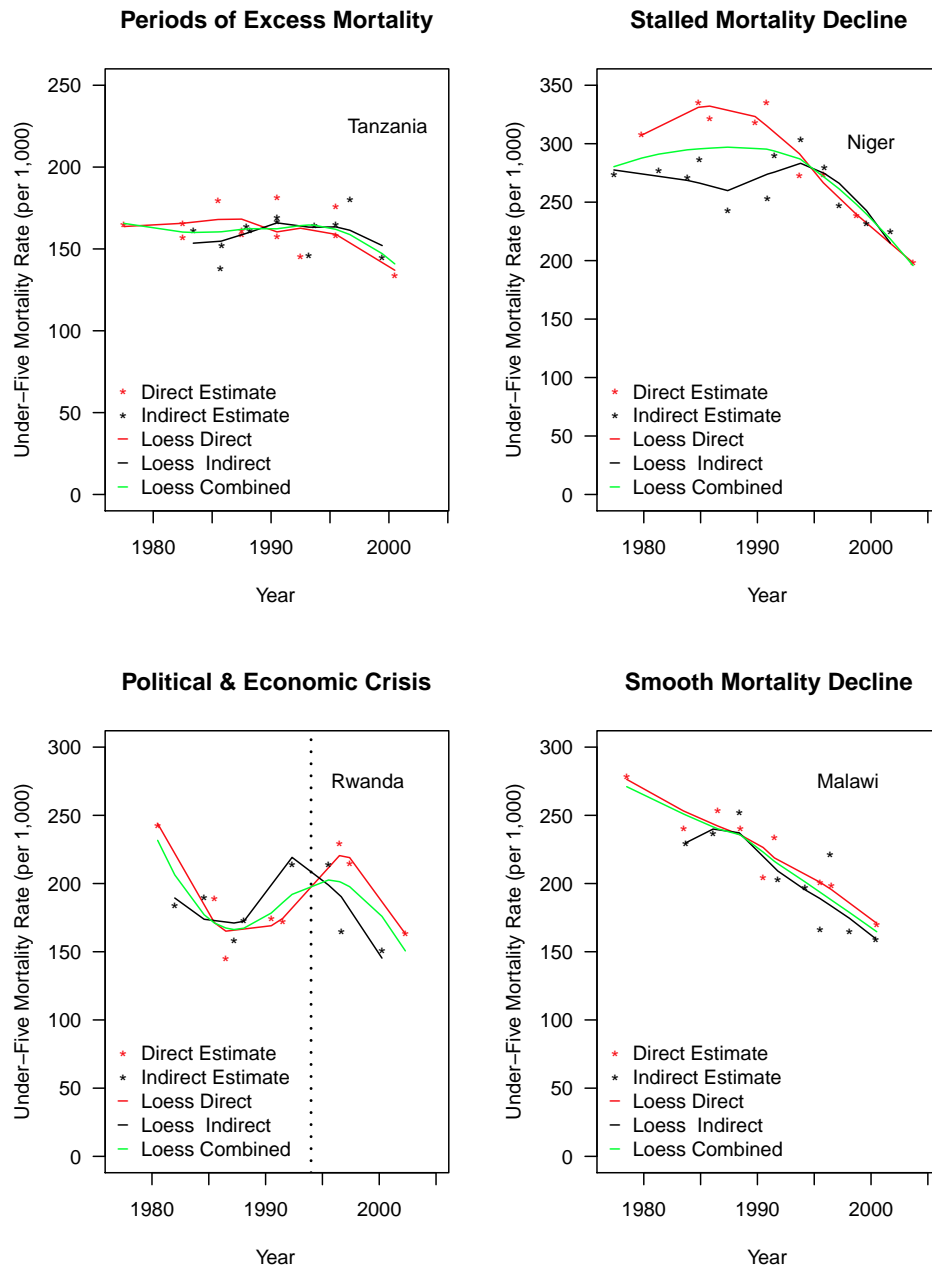


Figure 3.5: Differences in Estimated Trends of Adjusted Under-Five Mortality Rates for Example Countries Organized by Garenne & Gakusi (2006) Categories.

## Chapter 4

# Additional Issues in Indirect Estimation of Under-5 Mortality Rates

The brief chapter explores the associated differences between the Rajaratnam et al. (2010b) indirect method and the direct estimation method. The Rajaratnam et al. (2010b) method refines the classic Brass method by providing alternative approximations to the child's length of exposure to mortality, using cohort and period measures of the proportion of children ever born that have died, and modeling regional and country variation in the age pattern of fertility and mortality. For this evaluation, I compare indirect estimates from available census data and MICS surveys with direct estimates from full birth histories derived from DHS surveys with overlapping reference periods (to the census or MICS). This comparison is important as the Rajaratnam method, when developed, was validated against direct estimates from full birth histories. Thus evaluation of the Rajaratnam et al. (2010b) method by comparing indirect estimates compiled from sources other than DHS surveys provides an important reliability check. This check provides a means to evaluate the consistency of this revised indirect estimation method with direct estimates against the observed consistency between the classical Brass indirect method and direct estimates derived from full birth histories. In line with evaluations in the first part of this paper, I again use the Garenne and Gakusi (2006) characterizations of health and mortality transitions to characterize the types of errors and bias associated with statistically measurable inconsistencies between direct and indirect estimates.

### 4.1 Use of Synthetic Cohort Approaches

On some occasions, a full birth history data source is available for a reference period exactly five or ten years after a summary birth history data source (or another full birth history data source). In this situation, analysts can use these birth histories to construct synthetic cohorts to capture the mortality experience during the intersurvey period. This method is described in detail in (United Nations, 1983) and (Zlotnik and Hill, 1981).

Figure 4.1 displays the paired differences between direct estimates and indirect estimates calculated using the Trussell version of the Brass method (denoted as Brass-D in the graph), the intersurvey synthetic cohort method (denoted as ISC-D in the graph), and the Maternal Age Cohort (MAC) version of the Rajaratnam (2010) low cost method (denoted as MAC-D in the graph). This paired relative difference analysis is based on data from DHS surveys and IPUMS census files, where the intersurvey/census duration is five years. The data sources used in this analysis are listed in Table 5 of the Supplementary Appendix.

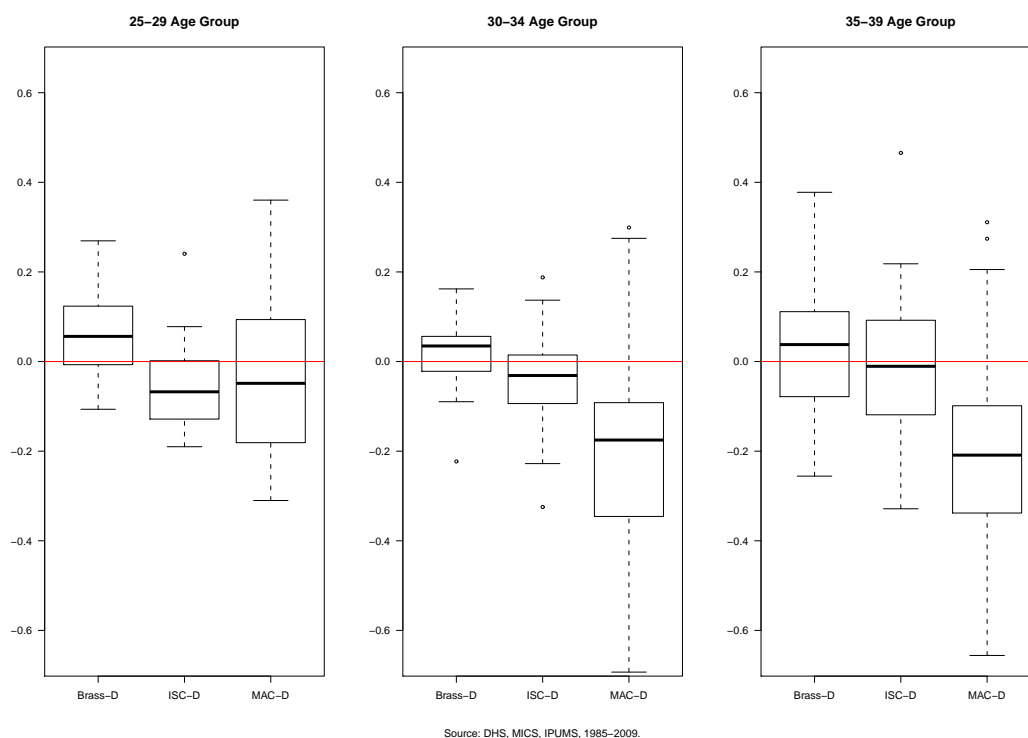


Figure 4.1: Estimated Relative Paired Differences for Under-Five Mortality Rates

The paired relative differences are, on average, smaller than those observed for general DHS data sources in Figure 3.3. This may be because countries with data available more regularly tend to have higher quality data. The paired relative differences between the Brass estimates and the direct estimates as well as those between the intersurvey synthetic cohort estimates are both small – on average less than 5%. Further, although the intersurvey synthetic cohort estimates are more consistent with direct estimates than the Brass estimates, the improvement in consistency (from the Brass estimates) is relatively small. This suggests that the impact of the Trussell method assumptions of recent linear mortality changes and constant fertility have relatively little impact for most countries for which there are two summary birth histories available separated by five

years. In fact, the difference in paired relative differences between direct/Brass estimates and direct/Intersurvey synthetic cohort estimates were larger for Rwanda (2000 & 2005) and Nigeria (2003 & 2008) than for the other countries in Table 5 – suggesting that intersurvey cohort estimates, when available, are preferable to classical Brass estimates for countries that have experienced any fertility change and non-linear mortality change in the recent past.

Somewhat surprisingly, the paired relative differences between the Maternal Age Cohort version of the Rajaratnam low-cost estimates and direct estimates are, in general, larger than those for the Brass and intersurvey synthetic cohort estimates. The main differences between these summary birth history methods are that the Rajaratnam et al. (2010) low cost method (i) does not rely on model life table patterns of mortality but instead fits a logit model for  ${}_5q_0$  to empirical data from DHS surveys, and (ii) incorporates cohort and period measures of the proportion of children dead into the estimation process.

## 4.2 Errors and Bias Associated with Under-Reporting of Births

Both full and summary birth histories are vulnerable to under-reporting of infant/child deaths. In this section, I outline the related errors and biases associated with under-reporting of births (and deaths) in retrospective surveys. I consider both first stage errors and second stage errors. I define first stage errors as those that result from a failure to sample or enumerate women whose birth histories are likely to be associated with child birth and death processes during recent time periods. Second stage errors are defined as errors resulting from limiting collection of birth histories to women aged between 15 and 49 at the time of the survey. This bias affects estimates for periods within 3-years of the time of the survey.

First stage errors are a product of inaccurate indirect sampling. Indirect sampling is used here, because there is no available sampling frame that directly covers all live births in recent times. As a result, researchers must indirectly sample this target population through a related population (in this case, the population of women aged 15 to 49 at the time of the survey).<sup>1</sup> In contrast, second-order errors result not from inaccurate (indirect) sampling but rather from errors in reporting by the sampled population.

In the case of birth histories used to measure under-five mortality rates, first-stage reporting errors take three main forms:

1. errors resulting from incomplete enumeration of the actual population of women aged between 15 and 49 years old at the time of the survey,

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<sup>1</sup>(Lavallée, 2007) defines indirect sampling in terms of two populations:  $U^A$  and  $U^B$ , where we wish to produce an estimate for  $U^B$  but unfortunately, we only have a sampling frame for  $U^A$ . In indirect sampling, the existing links between these two populations are utilized so that we can move from observed data from the population  $U^A$  to statistical inferences about the target population,  $U^B$ .

#### 4.2. *ERRORS AND BIAS ASSOCIATED WITH UNDER-REPORTING OF BIRTHS* 53

2. non-enumeration of women who may have experienced childbearing in the time-periods of interest but are not aged between 15 and 49 years old (eg women aged between 12 and 15 years old and those aged above 50 years old), and
3. errors resulting from when loss of children as a result of death or migration of mother are not reported.

In terms of non-enumeration of women who may have experienced childbearing but not fall between 15 and 49 years old during the time of the survey, the effect of the omission of women under 15 years old is small and only affects estimates referring to . Whereas the omission of women 50-years and above is mostly done because recall bias (in dating of events in a birth history and reporting of their own age) for women in these older age categories is thought to be substantial. A second shortcoming, and the empirical focus of this section, is the potential for transference of women from the 15-49 age group to other age groups to reduce an interviewer's workload. This phenomenon would lead to some women who are actually aged 15-19 years old at the time of the survey being documented as being 10-14 years old and some women aged 45-49 years old being documented as being 50-54 year old women.

Second-stage errors manifest themselves in two main ways:

1. Recall Lapse that results in non-reporting of a live-birth (Som, 1970; Pullum and Stokes, 1997) and
2. recall error that results in misreporting of a child's age, date of birth, and/or date of death (which may either be random or systematic error).

The literature on recall lapse points to potential differing effects. Garenne (1981), when examining birth histories collected from women in a demographic surveillance area, found that women did not forget their births to a large enough extent to produce measurable biases in under-five mortality rate estimates. Recall errors can arise for multiple reasons. If stillbirths are recorded as live births, this can bias the estimates since births and deaths will be overestimated. A second and possibly countervailing source of such recall error results from underreporting of neonatal deaths. Further, Prazak and Booth (1995) have reported that in some cultures in sub-Saharan Africa, when a child dies shortly after birth such a child is often not regarded as part of the family and when reporting on children ever born to the family, parents often do not include such children. The exclusion of such children in surveys and censuses may bias estimates of infant and child deaths downward. Another source of bias is mis-reporting of dates of births and deaths, which is common in societies where literacy rates are low (Sullivan et al., 1994a).

Errors resulting from a mother dying before the time of the survey are largely confined to populations that have experienced severe HIV epidemics. For that reason, in this paper we do not consider populations from Southern Africa.

In order to examine the relative magnitude of first stage under-reporting in full birth histories relative to summary birth histories, I compare estimated values of misreporting (as defined by the



4.2. ERRORS AND BIAS ASSOCIATED WITH UNDER-REPORTING OF BIRTHS 54

fitted values in Pullum (2006)) in full birth histories from the Demographic & Health Surveys and summary birth histories from UNICEF’s Multiple Indicator Cluster Surveys. The method used to quantify the magnitude of first stage under-reporting in full birth histories is described in the attached Supplementary Appendix. Figure 4.2 compares the omissions rates in birth history reports from DHS and MICS surveys for women aged 15-19 and 45-49 years old. Despite the considerably larger incentives in DHS surveys for omitting women from the birth history modules, there is very little difference in the omission rates in MICS and DHS surveys for women aged 15-19 years old. For women aged 45-49, the omission rates for both DHS and MICS are notably larger in magnitude than those for women aged 15-19 – perhaps reflecting the uniformly larger workload in documenting a birth history from a woman in her late forties compared with a woman who has just entered her childbearing years. But somewhat paradoxically, the omissions rates for 45-49 year old women from MICS survey summary birth histories are, in general, larger than those from DHS full birth histories.

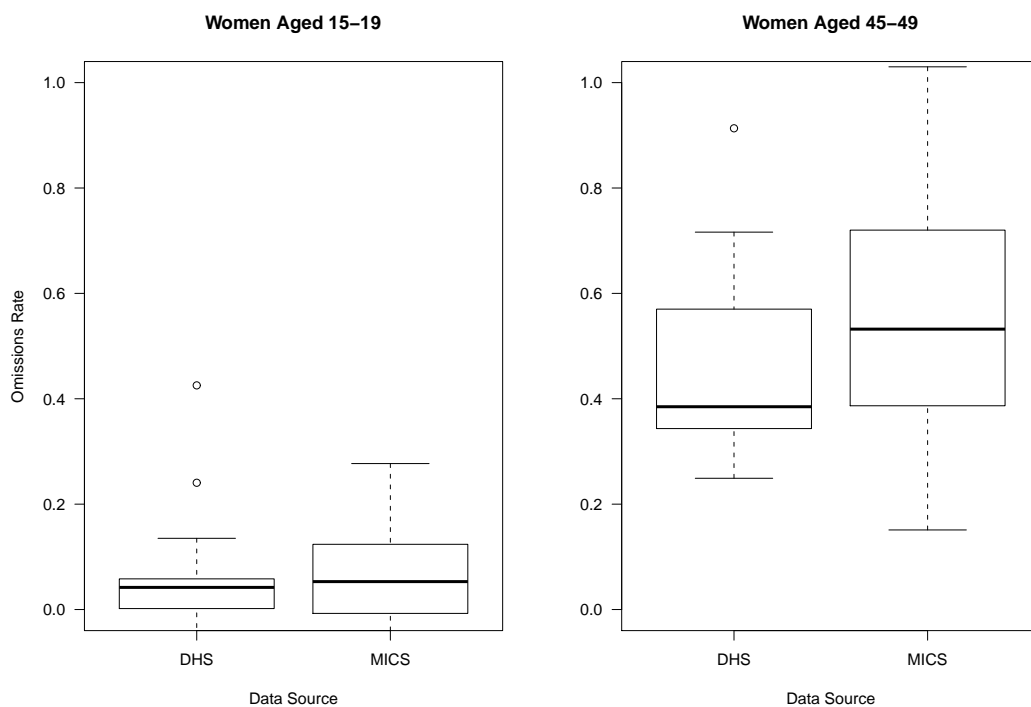


Figure 4.2: Estimated Omissions Rate of Women Aged 15-19 & 45-49 from comparable DHS and MICS Surveys

## Chapter 5

# Indirect Methods to Estimate Adult Mortality: Assessments of Reliability and Validity

With child mortality decreasing, an increasing proportion of all deaths in the developing world will occur at adult ages in the next decades. However, vital registration systems in many developing countries are incomplete and unreliable, and are thus not able to provide a solid basis for the estimation of adult mortality. As a result, demographers have had to rely on alternative methods such as death distribution methods (DDMs, eg the generalized growth-balanced method and synthetic extinct generations method) as well as survey methods that use data on the survivorship of close relatives (such as the sibling-survival method and orphanhood method). Yet the reliability and validity of these methods is not well understood. In this chapter, I use high quality household registration data from Liaoning province in China to assess the validity and reliability of these two broad adult mortality estimation methods. I use this household registration data as a validation dataset to gain insights into the performance of these adult mortality estimation methods in a low-resource setting.

### 5.1 Introduction

With child mortality decreasing and more countries moving through the early stages of the demographic transition, an increasing proportion of all deaths in the developing world will occur at adult ages in the next decades (Reniers et al., 2011). Over the last few decades, there has been a sustained focus on the adult mortality effects of the HIV/AIDS epidemic in sub-Saharan Africa (Feeney, 2001; Blacker, 2004). Maternal mortality, in particular, has also received increasing policy interest in recent years as part of the Millennium Development Goals and related initiatives (World Health Organization et al., 2010, 2012; Hogan et al., 2010). In resource-poor settings,

adult deaths threaten the livelihood of entire families and households, limit resources to the young and old, reduce the size of the labor force and result in social disruption. Thus, adult mortality is an important area of health research and policy development.

Accurate measurement of adult mortality in many developing countries is challenging. Few developing countries have functioning vital registration systems to measure adult mortality accurately (Mahapatra et al., 2007b). In sub-Saharan Africa, South Africa and Zimbabwe are notable exceptions, but by and large the rest of the region still faces considerable challenges and obstacles to overcome and address the difficult issues of vital registration set-up and maintenance (Feeney, 2001; Dorrington et al., 2001). In contrast, India and China have both developed sample registration systems. Even when there is reasonable vital registration coverage, the age reporting in the registration data is often inaccurate (Hill et al., 2005; Yang et al., 2005; Bhat, 2002).

As a result, demographers and statisticians have had to place heavy reliance on household surveys and population censuses and the use of indirect estimation methods. Yet these methods are rarely consistent (Preston, 1985; United Nations, 1992a; Adetunji, 1996; Silva, 2012). In particular, sibling-survival estimates appear to systematically under-estimate adult mortality relative to death distribution methods (DDMs) (Grassly et al., 2004; Garenne and Friedberg, 1997; Timaeus et al., 2001; Gakidou et al., 2004). However, DDMs themselves are subject to considerable measurement uncertainty – of the order of  $\pm 20\%$  (Murray et al., 2010). Official estimates of adult mortality are generally extrapolated from child mortality indices and model life tables: because of a lack of adequate vital statistics in many developing countries. Grassly et al. (2004) have noted that UN model-derived estimates are systematically higher than survey-based estimates that are derived from maternal and paternal orphanhood data. This discrepancy is most likely in part due to under-reporting in orphanhood histories collected in surveys and other associated errors and biases as well as adult mortality from causes other than AIDS being lower than assumed in the UN's models.

There is a long and well-developed literature on adult mortality estimation in situations where civil registration is absent or severely deficient. Hill (2003), United Nations (2008a) and Reniers et al. (2011) provide useful overviews of the scholarly and practitioner writings in this area. Given the paucity of high-quality, empirical data on adult mortality in developing countries, the United Nations Population Division has often derived adult mortality measures for such populations by combining child mortality estimates and model mortality schedules (United Nations, 2009, 2012). In India and China, where comprehensive vital registration is lacking at the national level, sample registration has been developed as an alternative approach to measure adult mortality (Yang et al., 2005; Bhat, 2002). However, for most developing countries, analysts rely on data from decennial censuses and household surveys for adult mortality estimation.

## 5.2 Objectives & Structure of Chapter

In this chapter, I seek to better understand the strengths and limitations of indirect adult mortality estimation methods that are widely used for contemporary populations where comprehensive vital registration is lacking. My focus is on two particular classes of methods: (i) death distribution methods that assess the relative completeness of death registration to census enumeration and (ii) indirect estimation methods that convert information about the survivorship of close adult relatives into standard life table functions.<sup>1</sup>

I draw on data from household registers from Northeast China and use these registers to examine the basic assumptions underlying the various indirect methods that can be used for adult mortality estimation. I regard these registers essentially as “validation data” that allow calculation of the true mortality schedules to which a population was subjected. Such validation data is often lacking in contemporary low-resource settings, where indirect methods are most often applied. Thus, by drawing on historical household registries I carry out a validation exercise of indirect methods that are widely-used in contemporary developing country situations.

Given the nature of the data and that the focus of my analysis is on the underlying indirect estimation models, I do not carry out an in-depth examination of reporting errors and their effects on the resulting indirect estimates. Such reporting errors have been examined previously by various authors: Bennett and Horiuchi (1984) have examined the effect of age reporting errors in general, Ewbank (1981) has examined the effect of age reporting errors on death distribution methods, whereas Elo and Preston (1994) use the SEG method to show the effects of age misreporting when estimating African-American mortality rates by direct methods in the United States.

This chapter is structured as follows. Section 5.3 provides a brief non-technical overview of the indirect adult mortality estimation methods examined in this chapter. Then, in Section 5.4, I review the Chinese household register data that I draw on in my analyses. Section 5.5 provides detailed mathematical description of the four main indirect adult mortality estimation methods. I examine the performance of the respective indirect estimates against the direct estimates from Chinese household register data in Section 5.6, then explore the different error and bias components that may explain the observed deviations from the direct estimates in Section 5.7.

This chapter, by exploiting high quality household registration data from historical China, explores the relative performance of three particular death distribution methods - namely the *Generalized Growth Balance Method (GGB)* and *Synthetic Extinct Generations (SEG) Method* - and two

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<sup>1</sup>Due to limitations of the data that I use, I am unable to investigate the accuracy of one-parameter models that use child mortality statistics, such as  ${}_5q_0$ , as the sole input to estimate adult mortality rates. Specifically, the Chinese historical data that I rely on are subject to substantial under-reporting errors for infant and childhood deaths (Lee and Campbell, 2011a).

particular indirect kinship-based estimation methods - namely the *Sibling Survivor Method* and the *Orphanhood Method*. I focus particularly on the following methodological challenges that can result in errors and biases in adult mortality estimates:

- “Survivorship bias effects” associated with the Orphanhood method. This survivorship bias occurs, as the survival of adults who have no living children is unrepresented in the reported proportions of parents alive (Hill and Trussell, 1977). Further, parents with more than one surviving child are over-represented in comparison to those with exactly one surviving child in proportion to the number of their surviving children. Thus, the method only produces unbiased results if the survival of the parents is unrelated to how many of their children are alive at the time that the data are collected (Trussell and Rodriguez, 1990).
- “Sibship death clustering effects” associated with the sibling survival method. To the extent that mortality clusters within sibships (i.e. sets of brothers or sisters born to the same mother), adult mortality estimates will be biased. Such sibship clustering occurs whenever deaths are more concentrated in a small proportion of sibships than would be expected by chance (Zaba and David, 1996).

### 5.3 Overview of Indirect Methods to Estimate Adult Mortality

The two most widely-used approaches, when comprehensive vital registration is lacking, are death distribution methods and estimation techniques based on the reporting of survivorship of close relatives. In this section, I provide a broad overview of these estimation methods as a means of providing motivation to the subsequent section that lays out the objectives of this chapter. More detailed and formal descriptions of these indirect methods are presented in Section 5.5.

#### Death Distribution Methods

Death distribution methods compare the age distribution of recorded deaths with the age distribution of the population being studied. They have the population balancing equation (shown in Equation 5.1) as their foundation, and assume that birth and death rates are constant during the interval, that net migration is either negligible or known, and that age reporting is accurate.

$$Population_{t+1} = Population_t + Births_t - Deaths_t + Net.Migration_t \quad (5.1)$$

There are three main death distribution methods that are used in situations where comprehensive vital registration is lacking: (i) the Generalized Growth Balance (GGB) method, (ii) the

Synthetic Extinct Generations (SEG) method, and (iii) a hybrid approach that iteratively applies both the SEG and GGB methods. These death distribution methods have been used widely in assessing the completeness of death registration and estimating adult mortality for populations that lack comprehensive vital registration (Murray et al., 2010; Bennett and Horiuchi, 1981; Hill and Thomas, 2007). The following paragraphs give a brief overview each of these three methods.

### **The Generalized Growth Balance Method**

The GGB method requires (i) the age-sex distribution of the population being studied at two separate time points (these are usually derived from two population censuses), and (ii) the count of annual deaths experienced by the population between the two time points. The method is underpinned by the following relationship derived from the demographic balancing equation:

$$\text{Birth.Rate} = \text{Population.Growth.Rate} + \text{Death.Rate} \quad (5.2)$$

By using the observed population growth rates, the observed birth rate and the observed death rate, the relative coverage of the population censuses can be estimated along with the relative coverage of the death registration process (Hill, 1987). The GGB method assumes a closed population (ie no migration), no age misreporting, and that the coverage across age groups is constant.

### **The Synthetic Extinct Generations Method**

The SEG method requires the same input data as the GGB method, namely (i) the age-sex distribution of the population being studied at two separate time points (these are usually derived from two population censuses), and (ii) the count of annual deaths experienced by the population between the two time points. In contrast to the GGB method, though, the SEG method is built on the fact that the number of living people of a given age must be equal to the number of people who will eventually die from the cohort born at the same time, from that time point until the cohort has completely died off (Bennett and Horiuchi, 1981, 1984). The method essentially compares the estimated future cohort deaths to the current cohort's population size as a means to assessing the completeness of the death registration process during the intercensal time period. The SEG method makes the same assumptions as the GGB method (ie assumptions of a closed population (ie no migration), no age misreporting, and that the coverage across age groups is constant) but also requires the additional assumption that coverage across the two censuses does not change.

### The GGB-SEG Hybrid Method

The GGB-SEG hybrid method requires the same data needed for the GGB method and the SEG method and makes the same assumptions as the SEG method, after necessary adjustments are made. The method, itself, involves application of the GGB method to the available data to adjust the raw data followed by application of the SEG method to the GGB-adjusted data. In particular, the GGB method is used to estimate the relative coverage of the two censuses and then adjust the population distributions prior to application of the SEG method. This initial application of the GGB method results in the SEG method assumption of constant coverage between the two censuses being able to be replaced by the assumption that GGB estimates of relative census coverage are unbiased (Hill and Choi, 2004).

## Indirect Adult Mortality Estimation Methods Based on Survivorship of Close Relatives

The second widely-used class of indirect adult mortality estimation methods uses survey-data on the survival of close relatives, such as parents or siblings, to estimate adult mortality statistics such as the probability of dying between ages 15 and 45, which is often denoted  ${}_{45}q_{15}$ . This class of methods was developed in a similar manner to Brass's child mortality estimation method using maternity histories on children ever born and children surviving - those methods are discussed in Chapter 3 of this dissertation. For adult mortality estimation, there are two primary methods of this type: the orphanhood method and the sibling survival method.

### The Orphanhood Method

The basic logic behind the orphanhood method is that the age group of survey respondents represents the survival duration of the parent. As a result, the proportion of respondents in a given age group with their parent (mother or father) alive at the time of the survey approximates a survivorship ratio. Figure 5.1 presents a lexis diagram representation of the orphanhood method in which  $N(x, t)$  respondents aged  $x$  years at time  $t$  report about the number of their mothers who are still alive at the time of survey,  $NO(x + a, t)$ . The basic method relies on the fact that the parents of a particular respondent are known to have been alive at the time of conception (for the father) or birth (for the mother) of the respondent. Thus, parents have been exposed to the risk of dying for a period equal to the respondent's age (for mothers) or age plus the gestation period (for fathers). The proportion of respondents of a given age group with a surviving parent is therefore an indicator of adult survival probabilities. The various methods that have been developed all model this relationship using various fertility and mortality models to convert the proportion with a surviving parent into a life table survivorship ratio, such as  $\frac{l_{x+25}}{l_x}$ . Brass and Bamgboye (1981)

and Palloni and Heligman (1985) developed methods to locate the adult mortality estimates in calendar time so that analysts could derive average temporal trends of adult mortality from the available orphanhood data.

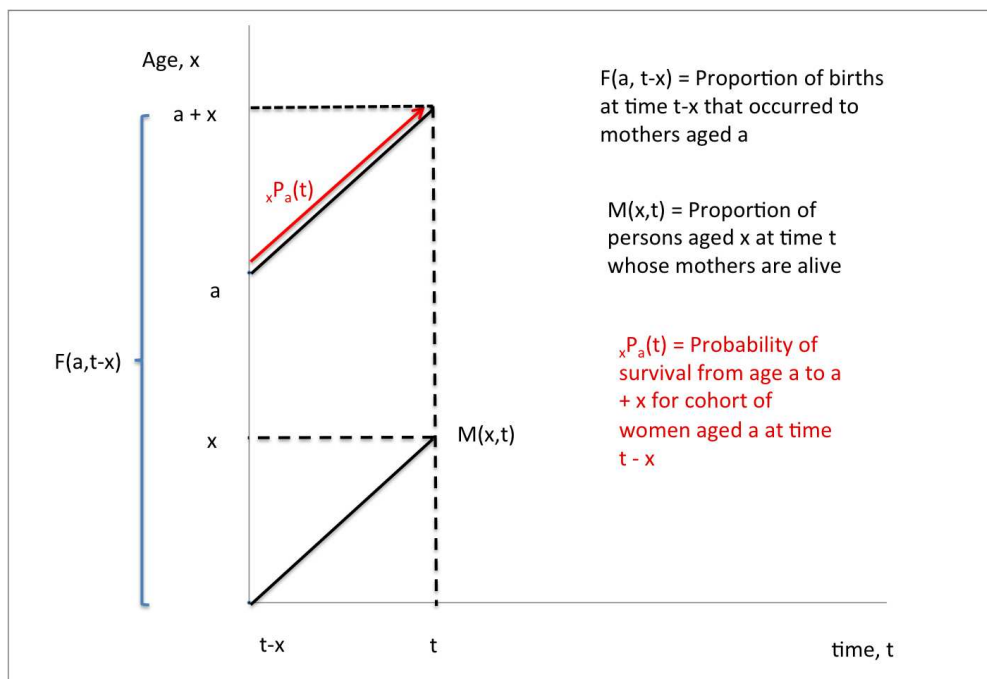


Figure 5.1: Lexis Diagram Representation of Orphanhood Method

### The Sibling Survival Method

The second approach that draws on data about the survivorship of close relatives, the sibling survivor method, was initially developed by Hill and Trussell (1977). The method exploits the closeness in ages of respondents and their siblings and uses the proportion of a respondent's siblings who are still alive as an estimator of life table survivorship of adults till the respondent's age conditional on their survival to age 15. Figure 5.2 provides a Lexis diagram schematic of the sibling-survival method. In a population whose underlying mortality has been changing, the estimated survivorship ratios reflect the mortality rates that have been experienced by each cohort at a range of ages and dates. However, these estimates can be located in calendar time by estimating how many years before the survey/census each cohort survival ratio equalled period survivorship.



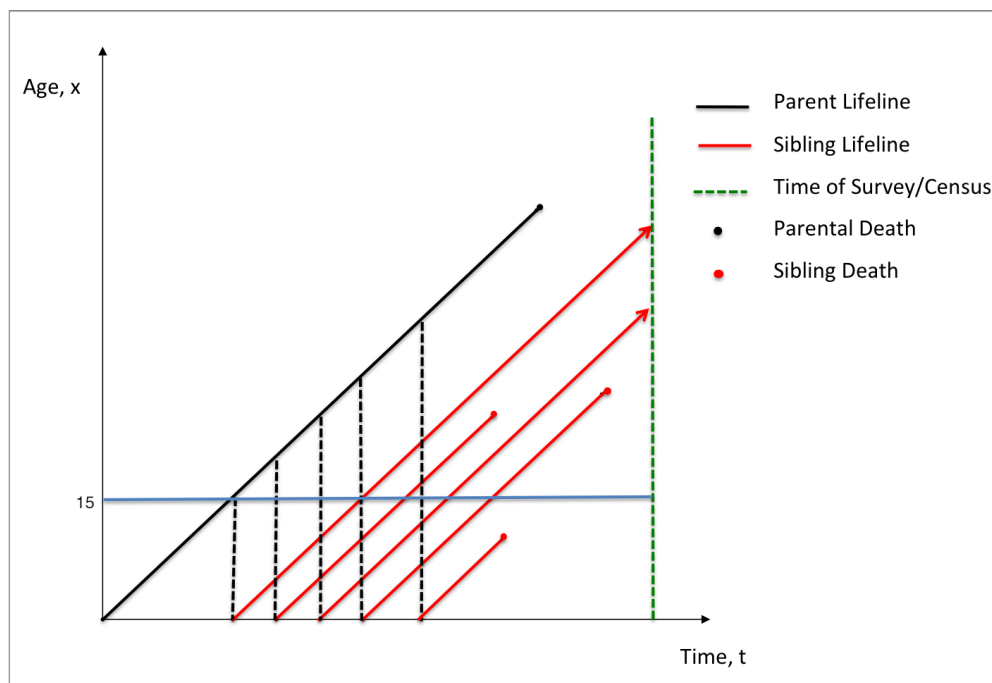


Figure 5.2: Lexis Diagram Representation of Sibling-Survival Method

## 5.4 Data Sources

In this chapter, in order to study the validity and reliability of different adult mortality estimation methods, I make use of household registers from northeast China. I use triennial household register data from 1789 to 1885 for more than 600 villages in Liaoning province (hereafter referred to as the China Multi-Generational Panel Dataset - Liaoning (CMGPD-LN)) (Lee and Campbell, 2011b).

The Liaoning registers (ie CMGPD-LN) consist of 1.5 million records describing approximately 260,000 people who lived in 28 administrative populations across 698 communities between 1749 and 1909. I limit my analysis to the subset of registers spanning 1789 to 1885 since (i) in 1789 the format of registries changed significantly (with more detail at the household-level being included in registers from 1789 onwards) and (ii) there are no surviving registers covering the period between 1888 and 1903. These registers resemble a series of triennial censuses in terms of their structure and organization. The population mainly consists of immigrants from Northern China who settled in rural Liaoning during the early eighteenth century, and their descendants. Entries were ordered by village and residential household. Households and their members appeared in almost the same order in each register, even when they moved to another village. The exten-

sive detail on household relationships, meanwhile, allows for location of kin and measurement of their characteristics. For each person in a household, the registers recorded relationship to household head; name(s) and name changes; adult occupation, if any; age; lunar year, month, day, and hour of birth; marriage, death, or emigration, since the last register, if any; and village of residence.

The ages of individuals, in the CMGPD-LN, were recorded in *sui* - a traditional form of reporting a person's age in China. Individuals were 1 *sui* at birth, and their age incremented every Lunar Year. On average, an age recorded in *sui* is 1.5 years higher than when reported according to Western conventions of recording age.

Historical demographers have already used these registers for the study of historical mortality patterns in China using event history analysis methods (Campbell and Lee, 1996, 2000, 2003, 2004). However, the comprehensive nature of these registration data have not yet been exploited to examine the performance of indirect estimation methods. Although, Campbell and Lee (2002) have directly analyzed the household patterns of widowhood and orphanhood mortality using event history analysis.

The CGMPD-LN is unique in that, through the application of both manual and automated record-linkage, the registers follow families across up to seven generations and reconstruct paternal kin networks living outside the household. As a result, basic vital and life course events for parents, children, sibling and other close kin are documented and linked. Hence, the CMGPD-LN provides a notably different validation framework than those that have been used in past validation studies of both direct and indirect estimation methods of both child and adult mortality methods. Previous validation studies have exploited regular census rounds in a demographic surveillance area and then supplemented these with a DHS-style survey that includes the retrospective collection of summary or full birth histories and sibling-survival histories [Insert citations here]. This framework has been effectively used to identify the nature and magnitude of different reporting errors associated with mortality events collected via retrospective surveys. The CMGPD-LN provides an internally consistent validation framework in that both the life table estimates and the indirect estimates are derived from the exact same data source - thus facilitating a focused assessment of errors associated with indirect methods. Also, the continuous updating of the Liaoning registers and thorough recording of kinship ties and survival status of kin further facilitates the direct examination of the underlying model assumptions of indirect adult mortality estimation methods - an area of inquiry that has only been studied via simulation methods to date [citep insert citations to simulation studies].

A notable limitation of these registers in relation to mortality analysis is that the registers do not record the precise date of death for an individual, but rather record whether or not a death occurred during an intercensal period (ie within the last 36 months for CMGPD-LN). The nature of this registration may result in some imprecision in the recording of ages at death in the form of

age overstatement, age understatement and symmetric age misreporting. Preston et al. (1999) have shown that such age misreporting biases older age mortality (for ages 80 and over) downwards, but has only small effects on adult mortality rates below age 60.

These Chinese household registers have some other notable limitations that need to be considered when using them for the study of mortality. First, children who died in infancy or early childhood were omitted from the registers. Thus infant and child mortality cannot be reliably estimated from these registers. Second, daughters are especially prone to omission from the registers, even when they survived. Taking these limitations into consideration, the focus of this chapter is on adult mortality using data available on males from the Liaoning household registers.

## 5.5 Methods

### Formal Description Death Distribution Methods for Estimating Adult Mortality

In this section, I present detailed formal descriptions of the death distribution methods I use to indirectly estimate adult mortality.

#### Generalized Growth Balance Method

Death distribution methods (DDMs) compare the distribution of deaths by age with the age distribution of living individuals and provide age patterns of mortality in a given reference period. There are three basic DDMs that are widely used: the generalized growth balance (GGB) method (Hill, 1987), the synthetic extinct generations (SEG) method (Bennett and Horiuchi, 1981, 1984) and a hybrid GGB-SEG method (Hill and Choi, 2004). These methods make several strong assumptions:

- that the population is closed to migration
- that the completeness of recording of deaths is constant by age,
- that the completeness of recording of population is constant by age for the GGB method and age and time for the SEG method, and
- that ages of the living and the dead are reported without error.

In these methods, age-specific growth rates are used to convert an observed distribution of deaths by age into the corresponding stationary population age distribution. In a stationary population the deaths above each age  $x$  are equal to the population aged  $x$ , since the deaths in the

stationary population above age  $x$  provide an estimate of the population of age  $x$ . The completeness of death registration relative to population is estimated by the ratio of the death-based estimate of population aged  $x$  to the observed population aged  $x$ . The synthetic estimate of the population aged  $x$  is given by:

$$\hat{N}(x) = \int D(y) e^{\int r(z) dz} dy \quad (5.3)$$

where  $N(x)$  is the population aged  $x$ ,  $D(y)$  is the observed number of deaths at age  $y$ , and  $r(z)$  is the age-specific growth rate of the population at age  $z$ .

The GGB method basically extends the demographic balancing equation to obtain the relative coverage of the first census to the second census as well as the relative completeness of death registration to census coverage. The demographic balancing equation expresses the identity that the growth rate of the population is equal to the difference between the entry rate and the exit rate. This identity holds for open-ended age segments  $x_+$ . The entry rate  $b(x_+)$  minus the growth rate  $r(x_+)$  provides a residual estimate of the death rate  $d(x_+)$ . We can then estimate the residual from population data from two population censuses and compared to a direct estimate using the recorded deaths (from the census or vital registration), and comparing these two records we can estimate the completeness of death recording relative to population (Hill and Choi, 2004).

Hill (1987) showed that

$$\frac{({}_5N_{1,x-5} \cdot N_{2,x})^{0.5}}{5 \cdot (N_{1,x+} \cdot N_{2,x+})^{0.5}} - \frac{1}{t} \ln\left(\frac{N_{2,x+}}{N_{1,x+}}\right) \approx \frac{1}{t} \ln\left(\frac{k_1}{k_2}\right) + \frac{(k_1 \cdot k_2)^{(0.5)}}{c} \cdot \frac{D(x^+)}{t \cdot (N_{1,x+} \cdot N_{2,x+})^{0.5}} \quad (5.4)$$

where  $N_1$  and  $N_2$  are population counts at two time points separated by  $t$  years,  $D$  are recorded intercensal deaths, and  $k_1$ ,  $k_2$ , and  $c$  are respectively the completeness of the first and second population counts and the intercensal deaths.

Hill and Choi (2004) suggested that the combination of SEG and GGB might be more robust than using either method by itself. The combined method consists of first applying GGB to estimate any changes in census coverage  $\frac{k_1}{k_2}$ , using the estimate to adjust one or other census to make the two consistent, and then applying SEG using the adjusted population data in place of the reported.

The basic logic of the Generalized Growth Balance (GGB) method is that for any open-ended age segment  $a_+$  of a closed population, the entry rate into the segment,  $b(a_+)$  is simply equal to the growth rate of the segment  $r(a_+)$  plus the death (or exit) rate  $d(a_+)$  of the segment. It follows that for a closed population the growth rate is equal to the birth rate minus the death rate, as shown in Equation 5.5.

$$r(a_+) = b(a_+) - d(a_+) \quad (5.5)$$

In a stable population, since the growth rate is constant for all age segments, then the entry rates and the death rates are separated by a constant. Hence, the entry rate into the population,  $\frac{N(a)}{N(a_+)}$ , the population growth rate,  $r$ , and the death/exit rate from the population,  $\frac{D(a_+)}{N(a_+)}$  have the following relationship:

$$\frac{N(a)}{N(a_+)} = r(a_+) + \frac{D(a_+)}{N(a_+)} \quad (5.6)$$

Hill (1987) has shown that this equation can then be further generalized for non-stable population settings, when there are multiple census enumerations available as follows:

$$\frac{N(a)}{N(a_+)} - r(a_+) = k + \frac{1}{c} \cdot \frac{D(a_+)}{N(a_+)} \quad (5.7)$$

where  $r(a_+)$  is the observed growth rate of the population aged  $a$  years and over, and  $k$  is the error in the growth rate resulting from a systematic change in coverage rates between censuses.

### Death Distribution Methods: Synthetic Extinct Generations Method

The second death distribution method, the Synthetic Extinct Generations (SEG) method, exploits the relationship that the number of living people of a given age must be equal to the number of people who die from the cohort born at the same time, from that time point until the cohort has completely died off. Bennett and Horiuchi (1984) generalized this to non-stable closed populations by noting that the population at age  $a$  can be estimated from the period deaths at all ages  $x$  (where  $x$  is greater than  $a$ ) by using age-specific growth rates to incorporate past demographic dynamics of the population, as shown in Equation 5.8:

$$N(a) = \int_{x=a}^w D(x) e^{\int_a^x r(y) dy} dx \quad (5.8)$$

where  $N(a)$  is the population aged  $a$ ,  $D(x)$  are the number of registered deaths at age  $x$ ,  $r(y)$  is the population growth rate at age  $y$ .

The completeness of death registration relative to that of census enumeration is then estimated by comparing observed population size to that estimated using Equation 5.8 as follows:

$$c(a) = \frac{\int_{x=a}^w D(x) e^{\int_a^x r(y) dy} dx}{N_o(a)} \quad (5.9)$$

The SEG method requires an additional assumption on top of those assumed by the GGB method, namely that the completeness of population enumeration does not change over time. Hill (2000) has noted that, when the assumptions of constant completeness of coverage of the censuses and reporting of deaths by age are reasonably valid, net in-migration is negligible, and age reporting is not affected by major distortions or anomalies, death distribution methods perform well.

### **Formal Description of Methods Based on Survivorship of Close Relatives for Estimating Adult Mortality**

In this chapter, we also explore two estimation methods that are based on the survivorship of close relatives: the orphanhood method and the sibling-survival method. Both methods have been used to collect adult mortality data in household surveys, such as the Demographic & Health Surveys, and population censuses. These methods are essentially extensions to the Brass indirect estimation method for child mortality estimation (Brass, 1964a, 1968, 1971a), which was the focus of Chapter 3 of this dissertation.

As noted in chapter 3, the methods based on reported information about the survival of close relatives – are an important subclass of indirect methods, alongside those based on intercensal survival techniques and death distribution approaches.

Relatives may be children, parents, spouses, or siblings of the respondent - leading to different sections of the age distribution of mortality to be estimated. These responses can then be used to find the portion of given relatives who are still living according to characteristics of respondents that reflect the risk period of survival of the relative, the current age of the respondent reflects the the risk period for the mother.

A major advantage of indirect estimation methods based on kin survivorship is that the respondent does not have to answer according to some time reference. The respondent simply needs to report the survivorship status of their relatives (eg whether or not their (biological) parents are alive).

Page and Wunsch (1976) found that such summary survival status is more accurately reported than complete survivorship data that includes dates of birth and dates of death (for deceased relatives) in addition to survival status. As discussed in chapter 3 of this dissertation and by Pullum (2006), full birth histories are subject to age heaping and birth transference problems which can

result in notable biases in direct child mortality estimates.

### The Sibling Survival Method

The sibling survival method uses retrospectively-collected sibling survivorship histories from adults above age 15 (DHS and other large survey programs usually collect these histories from adults between ages 15 and 49). Respondents are asked how many of their sisters/brothers lived to age 15 and how many of these sisters/brothers are still alive at the time of the census or survey. By tabulating the responses to these questions according to the respondent's age, analysts can then calculate the proportion still alive of sisters/brothers who were alive on their 15<sup>th</sup> birthday by five-year age group of respondent. Timaeus et al. (2001) specified regression coefficients  $a(n)$  and  $b(n)$  to convert proportions still alive after their 15<sup>th</sup> birthday aged  $n - 5$  to  $n$ , denoted by  ${}_5S_{n-5}$ , to age-based probabilities of survivorship according to:

$${}_{n-15}p_{15} = a(n) + b(n) {}_5S_{n-5} \quad (5.10)$$

By fitting a 1-parameter relational logit model life table to each estimated survivorship probability,  ${}_{n-15}p_{15}$ , the survivorship probabilities can then be converted into a common adult mortality metric - such as  ${}_{45}q_{15}$ ,  ${}_{35}q_{15}$ , or  ${}_{25}q_{15}$ .

Orphanhood estimates can be derived in a similar way to sibling survival estimates from retrospectively collected information on survivorship of the parents of adult respondents aged less than 50. To derive adult mortality estimates from orphanhood survivorship information, the following are tabulated: (i) the proportion of respondents whose mother/father is alive by five-year age groups, (ii) the number of births in the year before the survey/census tabulated by five-year age groups of the women giving birth, and (iii) (for estimation of male adult mortality) the difference between the median ages of currently married men and women.

Timaeus (1992) specified the following regression equation for converting parental survivorship proportions between age 25 and  $25 + n$  (where  $n > 0$ ) into common mortality indices:

$${}_n p_{25} = a(n) + b(n) \cdot \bar{M}^f + c(n) {}_5S_{n-5} \quad (5.11)$$

where  $\bar{M}^f$  represents the mean age at childbearing, and is estimated directly from the data, A 1-parameter relational logit model can then be fitted to the survivorship proportions to derive adult mortality rate indices.

In a stable population, the number of siblings ever born  $y$  years before a respondent who is currently aged  $a$  can be written as:

$${}_aV_y = \begin{cases} \int_s^w e^{-r(z-a)} f(z) \cdot l(z) \cdot f(z-y) dz & y \geq 0 \\ \int_s^w e^{-r(z-a)} f(z) \cdot l(z-y) \cdot f(z-y) dz & y < 0 \end{cases}$$

where  $y \geq 0$  relates to older siblings and  $y < 0$  to younger siblings; integration is over the entire age period of childbearing;  $z$  is the age of the mother at the birth of the respondent;  $f(z-y)$  is the probability of the respondent's mother giving birth at age  $z-y$  conditional on having given birth to the respondent at age  $z$  (ie  $f(z-y)$  is the distribution of ages at birth of an individual woman); and  $r$  is the stable population growth rate. Then, the proportion of siblings still alive among those respondent who survived to age 15, in five-year age groups  $x$  to  $x+5$ , is given by:

$${}_5S_x = \frac{\int_x^{x+5} l(a) \int_{15-a}^{w-s} {}_aV_y l(a+y) dy da}{l(15) \int_x^{x+5} l(a) \int_{15-a}^{w-s} {}_aV_y dy da}, x \geq 15 \quad (5.12)$$

### Indirect Orphanhood Method

The indirect orphanhood method was first introduced by Hill and Brass (1973) and Brass (1975). The basic approach uses a weighted average of the proportions of respondents in 5-year age groups whose parents are still alive, whereby the weights adjust for the mean age of childbearing, to calculate life table survivorship statistics.

If we assume that a survey is conducted at time  $t$  in which the survivorship of parents (ie orphanhood status of respondents) is collected. The number of births  $T$  years prior to the survey is given by the product of the number of women  $T$  years ago by age and their age-specific fertility rates  $T$  years ago:

$$B_{t-T} = c(a, t-T) \cdot f_{t-T}(a) \quad (5.13)$$

If the population is stable, with a constant rate of growth,  $r$ , then the number of women  $T$  years ago aged  $a$  years can be written as:

$$c(a, T) = B_t \cdot e^{-r(a+T)} l_{a+T}(a) \quad (5.14)$$

where  $B$  denotes the current number of births and  $l_{a+T}(a)$  denotes the proportion of women born  $a+T$  years ago who survived to age  $a$ .



The number of women who,  $T$  years ago, became mothers at age  $a$  and survived to the time of the survey is given by  $c(a, T) \cdot n \cdot f_a \frac{l_{a+T}(a+T)}{l_{a+T}(a)}$ , where  $l_{a+T}(a+T)$  is the proportion of women born  $a+T$  years prior to the survey.

The number of women who gave birth  $T$  years ago at age  $a$  and who survive to the time of the survey is given by:

$$W_S(a, T) = B_t \cdot e^{-r(a+T)} f(a) l_{a+T}(a+T) \quad (5.15)$$

The total number of mothers  $T$  years ago at age  $a$  is:

$$W_T(a, T) = B_t \cdot e^{-r(a+T)} f(a) l_{a+T}(a) \quad (5.16)$$

Thus, the proportion of mothers who gave birth  $T$  years ago and survive to the time of the survey is given by  $P(T)$ :

$$P(T) = \frac{\int W_S(a, t) da}{\int W_T(a, t) da} = \frac{\int B_t \cdot e^{-r(a+T)} f(a) l_{a+T}(a+T) da}{\int B_t \cdot e^{-r(a+T)} f(a) l_{a+T}(a) da} \quad (5.17)$$

This model assumes approximate independence between the mother's probability of surviving and the probability of survival of the child.

In order to convert the proportion of mother's surviving,  $P(T)$ , into a standard mortality statistic, we need to estimate the age distribution of mothers at the time of childbearing,  $M$ :

$$M = \frac{\int a \cdot e^{-r(t+a)} \cdot f(a) \cdot l(a) da}{\int e^{-r(t+a)} \cdot f(a) \cdot l(a) da} \quad (5.18)$$

Hence, by deriving or assuming model fertility and mortality schedules, one can then estimate  $P(T)$  and  $M$ . Hill and Brass (1973) then specified the following regression model to estimate a traditional life table statistic:

$$\frac{l(25+t)}{l(25)} = a + b \cdot M + c \cdot P(t) \quad (5.19)$$

The regression coefficients,  $a$ ,  $b$ , and  $c$ , were estimated by Hill and Trussell (1977) using a wide range of model fertility and mortality schedules.

Brass and Bamgboye (1981) have extended this approach to locate the adult mortality estimates in calendar time so that analysts can derive average temporal trends of adult mortality. They have

noted that the proportion of respondents aged whose mothers have survived to the time of the survey,  $S(a)$ , given by

$$S(a) = \frac{l(a) \int_s^w c(a, y) \frac{l(y+a)}{l(y)} dy}{l(a) \int_s^w c(a, y) dy} \quad (5.20)$$

can be rewritten as a weighted average of cohort survivorship ratios:

$$S(a) = \int_s^w {}_a v_x^c \cdot {}_a p_x^c dx \quad (5.21)$$

where  ${}_a v_x^c = \frac{c(a, x)}{\int_s^w c(a, x) dx}$  ( ${}_a v_x^c$  is the contribution to  $S(a)$  from parents who bore children at age  $x$  - ie children now aged  $a$ ).

This time location method aims to estimate the time  $T$  at which the cohort measure of survival,  ${}_a v_x^c$ , equals the equivalent period measure,  ${}_a p_x(T)$ , such that  $S(a) = \int_s^w {}_a v_x^c {}_a p_x(T) dx$ . An approximate expression for cohort survivorship in period terms can be derived via a Taylor series expansion about  $T$ , such that:

$$\ln({}_a p_x^c) = \int_x^{x+a} \mu(y, T) dy - \int_x^{x+a} (y - (x + a) - T) \mu'(y, T) dy \quad (5.22)$$

where  $\mu'(y, T)$  is the first derivative of the force of mortality,  $\mu(y, t)$  evaluated at  $T$  with respect to time.

If there is a constant relationship between the rate of change in the force of mortality with time for a fixed age and the rate of change in survivorship with age for time, the cohort survivorship ratio can then be written as:

$$\ln({}_a p_x^c) = \ln({}_a p_x(T)) - K \int_x^{x+a} (y - (x + a) - T) \frac{d}{dy} l(y, T) dy$$

Brass and Bangboye (1981) showed that this differential between  $\ln({}_a p_x^c)$  and  $\ln({}_a p_x(T))$  approaches zero, at the following time,  $T$ :

$$T = \frac{\int_y^{y+5} l(a) \int_s^w {}_a v_x \cdot {}_a p_x(T) (a \cdot l(x, T) - {}_a L_x(T)) dx da}{\int_y^{y+5} l(a) \int_s^w {}_a v_x \cdot {}_a p_x(T) (l(x, T) - l(x + a, T)) dx da} \quad (5.23)$$

where  ${}_a L_x(T) = \int_x^{x+a} l(x, T) dx$ ,  $(l(x, T) - l(x + a, T))$  is the number of deaths between ages  $x$  and  $x + a$ , and  $(a \cdot l(x, T) - {}_a L_x(T))$  is the person-years lived by those who died between ages  $x$  and  $x + n$ .

## 5.6 Validation Analysis of Indirect Estimates

Table 5.1 presents summary results of the validation analysis of the four indirect estimation methods using the CMGPD-LN register data. This validation analysis compares the respective indirect estimates to corresponding life table estimates. These comparisons of indirect estimates are made with the 95% confidence intervals associated with the life table estimates. The point estimates for  ${}_{45}q_{15}$  and corresponding confidence intervals were derived using the following formulae described in Chiang (1984):

$$\hat{q}_i = \frac{n_i M_i}{1 + (1 - a_i) n_i M_i} \quad (5.24)$$

$$M_i = \frac{D_i}{P_i} \quad (5.25)$$

where  $\hat{q}_i$  is the probability that an individual will die in the  $i$ th interval,  $n_i$  is the length of the interval,  $M_i$  is the death rate in the interval (i.e. the number of individuals dying in the interval ( $D_i$ ) divided by the mid-year population ( $P_i$ ), which is the number of years lived in the interval by those alive at the start of the interval, i.e. it is the person-time denominator for the rate), and  $a_i$  is the fraction of the last age interval of life.

The results in Table 5.1 show that the estimates from the four indirect methods differ substantially from the life table validation estimates of  ${}_{45}q_{15}$ , but in different ways. Out of the four indirect methods, the orphanhood method yields the estimates that are, on average, most consistent with the life table estimates of  ${}_{45}q_{15}$ . Almost 80% of the orphanhood point estimates lie within the 95% confidence interval associated with the life table  ${}_{45}q_{15}$  estimates. In contrast, the GGB and SEG methods perform similarly whereby only half of the resulting indirect point estimates fall within the 95% confidence interval associated with the life table  ${}_{45}q_{15}$  estimates. The sibling-survivor

estimates tend to systematically under-estimate  ${}_{45}q_{15}$ , whereby more than half of the indirect point estimates fall below the 95% confidence interval associated with the life table  ${}_{45}q_{15}$  estimates. This finding is consistent with previous work by Stanton et al. (2000) that, comparing unadjusted sibling-survival estimates from the World Fertility Surveys to model mortality schedules, suggested the sibling-survival estimation method tends to under-estimate adult mortality. Further, these findings are consistent with evaluation of the indirect orphanhood method applied to data reported by young adults. These findings show that, aside from reporting errors and data quality problems, the method produces estimates that are fairly consistent with direct estimates and vital registration-based estimates (Timaeus, 1992). More recently, Luy et al. (2011); Luy (2012) have shown, using multi-round health surveys in Italy, that adult mortality differentials by education levels and occupation estimated using indirect orphanhood methods are consistent with direct methods.

Figures 5.3, 5.4, 5.5, and 5.6 display the temporal pattern of the four indirect estimates in comparison with the life table estimates of  ${}_{45}q_{15}$ . The sibling-survival and orphanhood estimates tend to smooth out the localized variation in the adult mortality estimates over time. This smoothing out process is a direct result of such indirect estimates essentially being weighted averages of cohort survivorships, as shown in Section 5.5. There is however variation in the relative differences between the life table estimates and the orphanhood estimates. Relative differences between  ${}_{45}q_{15}$  estimates associated with reports associated with 10-14 and 15-19 year olds tended to be lower than the associated life table estimates, compared with those from 0-4, 20-24, 25-29 and 30-34 year olds.

## 5.7 Examination of Errors and Bias

### Orphanhood Estimates

Orphanhood data has been widely collected in population censuses and household survey programs (most notably the Demographic & Health Surveys and its predecessor, the World Fertility Surveys). The indirect orphanhood method makes the following implicit and explicit assumptions:

1. orphanhood status is accurately reported by respondents,
2. the survival of parent's is assumed to be independent of the survival of their children,
3. the age distribution of parents is assumed to be approximately stable,

Table 5.1: **Summary Statistics of Validation Analysis of Indirect Adult Mortality Estimates.** Mean relative error (MRE), mean absolute relative error (MARE), the percentage of estimates with an absolute relative error (ARE) of more than 0.15, and the percentage of estimates for which the indirect estimate falls below/within/above the 95% confidence interval of the corresponding life table-based estimate of  ${}_{45}q_{15}$ .

Method	N	Mean Errors		% of Estimates			
		MRE	MARE	ARE < .15	Below 95% CI	Within 95% CI	Above 95% CI
<b>DDM</b>							
GGB	33	-.02	.21	51.6	21.2	51.5	27.3
SEG	33	-.08	.24	51.5	12.1	51.4	36.4
<b>Kin-based</b>							
Orphanhood	198	.07	.11	82.1	0.6	79.5	19.9
Sibling-Survival	198	-.33	.34	78.3	54.6	40.4	0.0

Source: CMGPD-LN, 2012

4. the age pattern of mortality for the population being studied can be approximated by standard model life tables,
5. the probability of a parent's survival status being reported by a single surviving child is independent of the number of children the parent is survived by, and
6. the survivorship statistics can be accurately located in calendar time (Timaeus et al., 2001).

Many researchers have focused heavily on reporting errors associated with the orphanhood method. In particular, they have noted that reporting errors, such as adoption effects can contribute notable bias to resulting indirect mortality estimates. The adoption effect occurs when adopted individuals under-report the mortality of their parents, as they interpret survey questions about parental survival to relate to their living (adopted) parents, as opposed to their (deceased) biological parents. This measurement error is challenging, as respondents may not be willing to disclose if the parent's they are reporting on are their biological parents. Further, survey enumeration teams may not want to jeopardize rapport with the respondent by probing about whether the parent being reported is a biological or adopted parent (Blacker et al., 1986). Several authors, examining orphanhood modules used as part of household surveys, have noted how such an adoption effect can lead to notable under-estimation of adult mortality (Timaeus, 1986; Blacker, 1977). In the

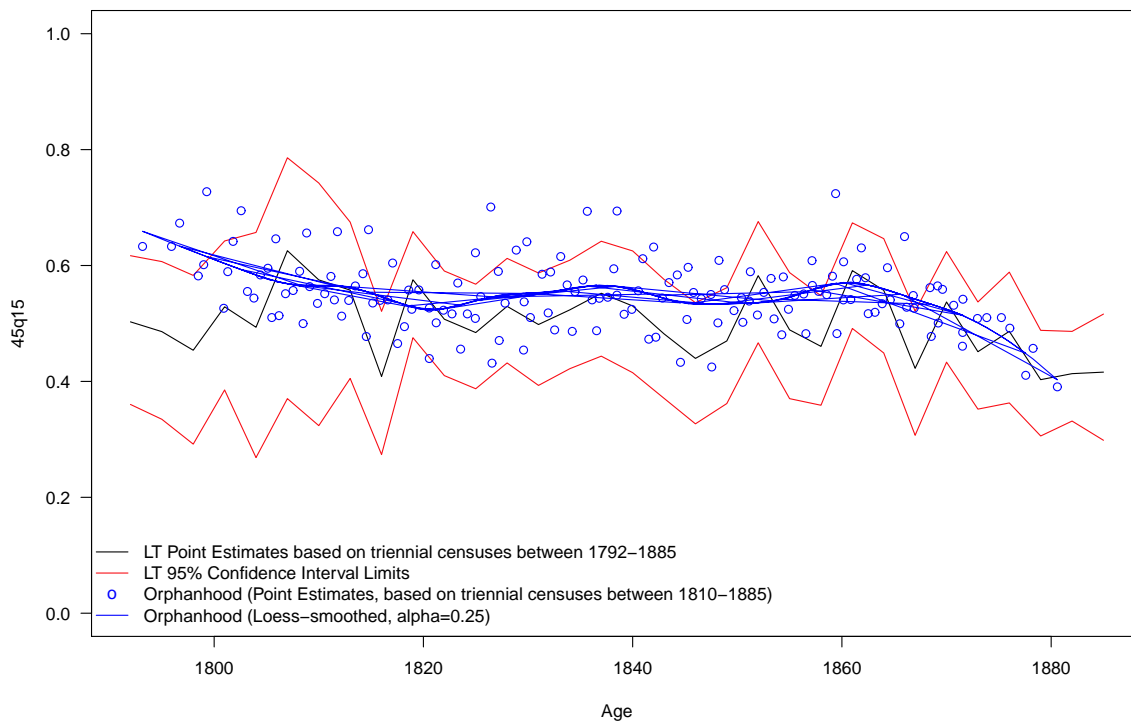


Figure 5.3: Comparison of Estimates of  ${}_{45}q_{15}$  derived using the Indirect Orphanhood Method with corresponding Life Table Validation Estimates & Confidence Intervals, 1792-1885

CMGPD-LN registers, there were 266 adoptions (referred to as *guoji* in Chinese) registered. This represented 0.02% of registered individuals and thus the effect of any actual adoption effect would be negligible for CMGPD-LN adult mortality estimates using the orphanhood method. Hence, given the negligible adoption effect and the continuous and high quality reporting of vital events in the CMGPD-LN registers, the focus of this analysis is on the effect of simplifying model assumptions on resulting adult mortality estimates.

When applying the orphanhood method survivorship bias can result, as survival of adults who have no living children is unrepresented in the reported proportions of parents alive (Hill and Trussell, 1977). Further, parents with more than one surviving child are over-represented in comparison to those with exactly one surviving child in proportion to the number of their surviving children. Thus, the orphanhood method only produces unbiased results if the mortality of parents is unrelated to how many of their children are alive at the time that the data are collected (Trussell and Rodriguez, 1990).

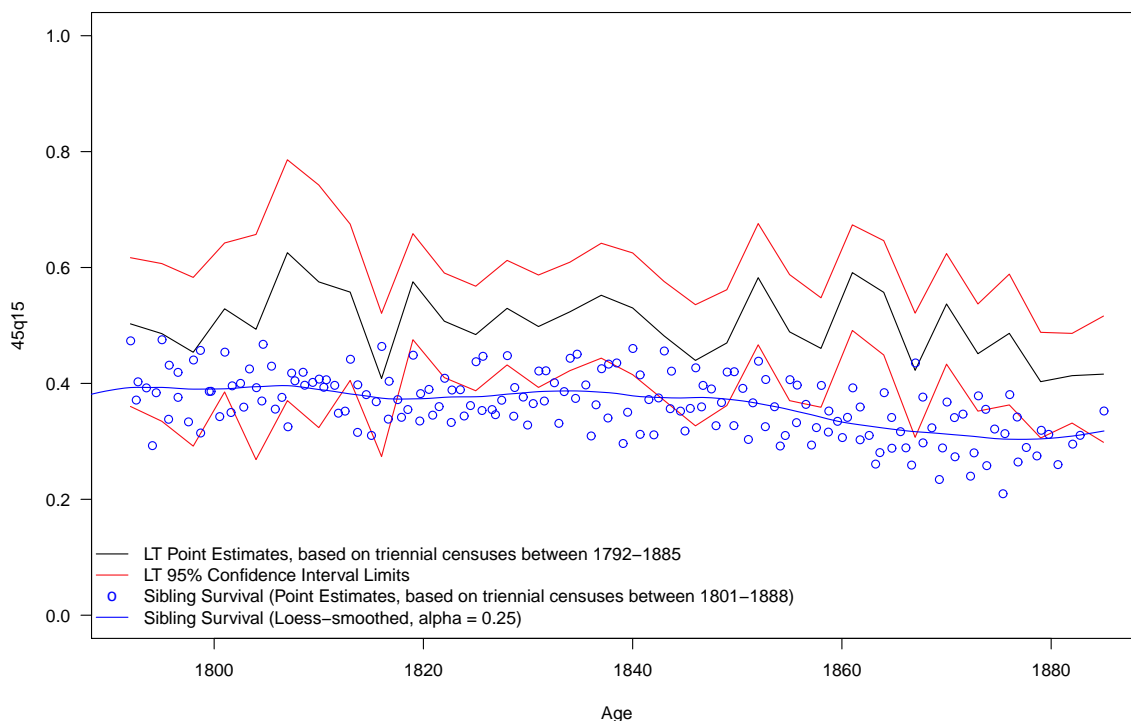


Figure 5.4: Comparison of Estimates of  ${}_{45}q_{15}$  derived using the Indirect Sibling-Survival Method with corresponding Life Table Validation Estimates & Confidence Intervals, 1792-1885

The orphanhood method is also vulnerable to a multiple reporting bias, whereby parents who live longer have more children and therefore have a higher density of reporting than those who die earlier. In Table 5.2, I examine orphanhood estimates by surviving parity (ie the number of children alive at the time of data collection) against the classical orphanhood estimates. We observe that parity-based orphanhood estimates derived using the CMGPD-LN, similar to standard orphanhood estimates, suffer from systematic bias. In particular, we observe that the bias decreases as the number of surviving children at the time of the survey increases. These disaggregated estimates point to the size of the bias resulting from differential reporting based on parental longevity and fertility. We also note that using only orphanhood data reported by firstborn children, as suggested by Rutenberg et al. (1990), tends to over-estimate adult mortality relative to life table style estimates - even more so than the standard estimation method for the CMGPD-LN data. This finding is consistent with work by Trussell and Rodriguez (1990) that showed that (i) restriction of the sample to one respondent per sibship results in a systematic upward bias, (ii) the actual bias in the indirect

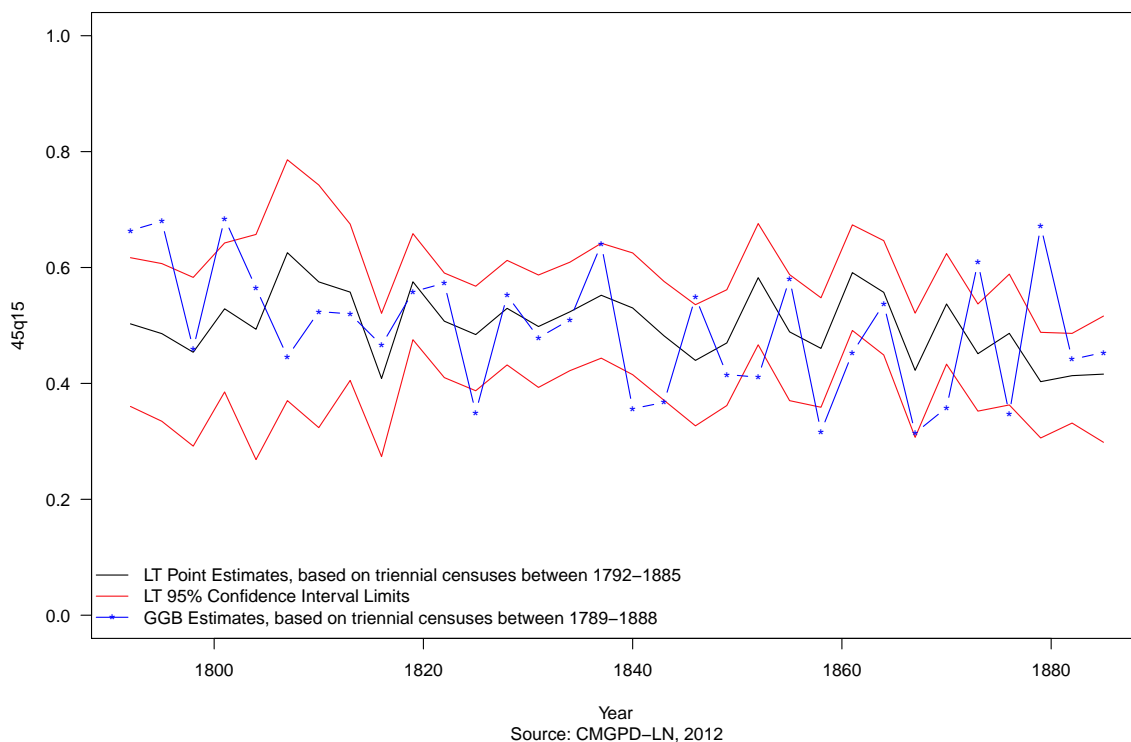


Figure 5.5: Comparison of Estimates of  ${}_{45}q_{15}$  derived using the Generalized Growth Balance (GGB) Method with corresponding Life Table Validation Estimates & Confidence Intervals, 1792-1885

orphanhood estimate is dependent on the probability of an adult death and sibship size, and (iii) inclusion of all surviving siblings in the sampling and estimation for orphanhood estimates results in the least biased estimates.

Another key problem with parental survivorship data is the implicit relation between fertility and mortality. Women who survive longer (throughout their reproductive years), on average, produce more offspring. As a result, mother's survival status is associated with a higher probability of reporting (by her children). [Thus the proportion of non-orphans is affected by a self-selection of higher fertility women: respondents will be drawn disproportionately from mothers from low mortality groups.] Thus respondents will be disproportionately drawn from sibships associated with mothers from low mortality groups. This will result in the estimated proportion surviving,  $PS(x + 25|25)$ , being upwardly biased due to selection effects. As the age of the respondent decreases, the mortality level associated with  $PS(x + 25|25)$  is increasingly affected by the upwards



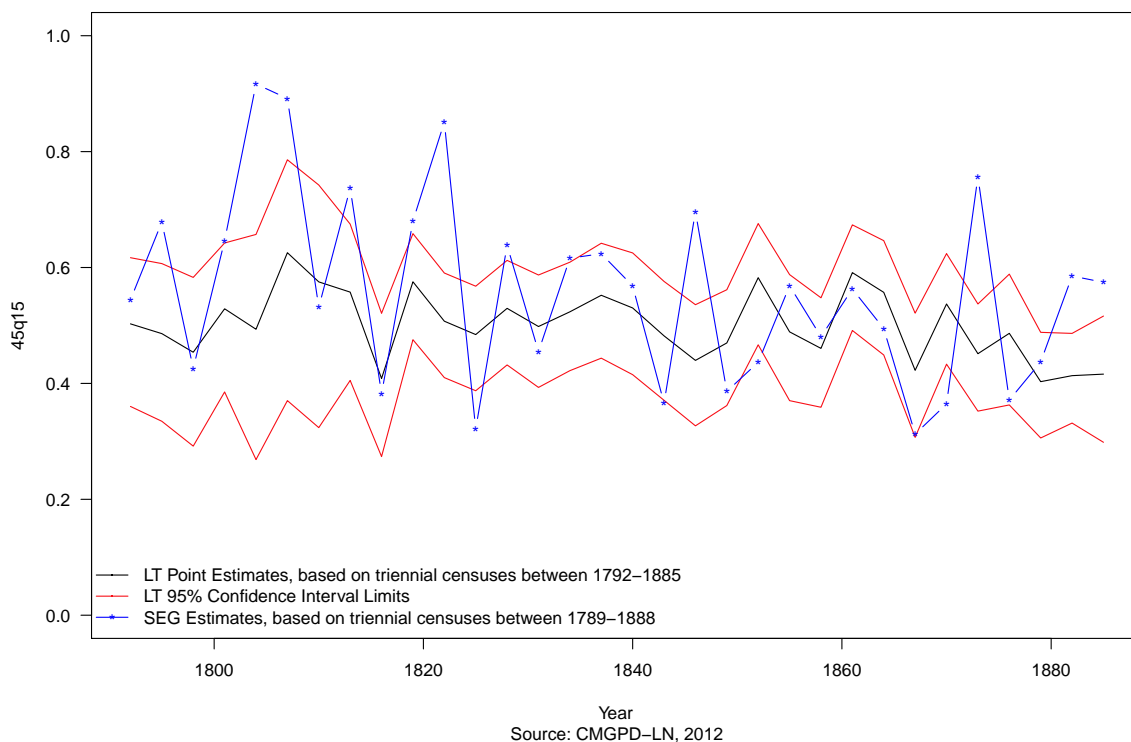


Figure 5.6: Comparison of Estimates of  ${}_{45}q_{15}$  derived using the Synthetic Extinct Generations (SEG) method with corresponding Life Table Validation Estimates & Confidence Intervals, 1792-1885

bias: resulting in a misleading estimated effect of accelerated mortality decline.

Pison and Langaney (1985), by validating a census in Eastern Senegal with genealogical survey data, found that maternal orphans overwhelmingly reported their orphanhood status correctly. Robertson et al. (2008) also reviewed the consistency of parental survival reporting in successive rounds of a cohort study in Manicaland, Zimbabwe. They found that 86.6% of paternal orphans consistently reported their parent's survival status across success survey rounds.

Women who survive longer (throughout their reproductive years), on average, produce more offspring. As a result, mother's survival status is associated with a higher probability of reporting (by her children). Thus the proportion of non-orphans is affected by a self-selection of higher fertility women: respondents will be drawn disproportionately from mothers from low mortality groups. The following conceptual example describes the dynamics of this selection effect: Imagine

Table 5.2: **Summary Statistics of Validation Analysis of Unadjusted and Adjusted Indirect Adult Mortality Estimates.** Mean relative error (MRE), mean absolute relative error (MARE), the percentage of estimates with an absolute relative error (ARE) of more than 0.15, and the percentage of estimates for which the indirect estimate falls below/within/above the 95% confidence interval of the corresponding life table-based estimate of  ${}_{45}q_{15}$ .

Method	N	Mean Errors		% of Estimates			
		MRE	MARE	ARE < .15	Below 95% CI	Within 95% CI	Above 95% CI
<b>DDM</b>							
<b>GGB</b>							
- 3-year span	33	-.02	.21	51.6	21.2	51.5	27.3
- 6-year span	32	-.07	.21	78.1	25.0	53.1	21.9
- 9-year span	31	-.05	.19	83.4	25.8	51.6	22.6
- 12-year span	22	-.08	.18	90.9	27.3	54.5	22.7
<b>SEG</b>							
- 3-year span	33	-.08	.24	51.5	12.1	51.4	36.4
- 6-year span	32	-.09	.22	56.3	21.9	53.1	28.1
- 9-year span	31	-.11	.21	58.1	16.1	54.8	25.8
- 12-year span	22	-.10	.25	59.1	18.2	54.5	27.3
<b>Kin-based</b>							
<b>Orphanhood</b>							
- Standard	198	.07	.11	82.1	0.6	79.5	19.9
- Firstborn-only	198	.02	.16	86.3	5.7	68.6	25.7
- Parity-1	198	.06	.18	97.1	5.7	53.1	41.4
- Parity-2	198	-.001	.15	97.7	8.0	71.4	20.6
- Parity-3	198	.004	.12	97.5	2.3	78.3	19.4
- Parity-4+	198	.06	.14	98.3	2.3	85.7	12.0
<b>Sibling-Survival</b>							
- Standard	198	-.33	.34	78.3	54.6	40.4	5.0
- $\frac{1}{S_i}$ -weighted	198	.06	.17	51.6	5.7	64.6	29.7
- $\frac{B_i}{S_i}$ -weighted	198	.07	.15	53.1	3.6	68.8	27.6

Source: CMGPD-LN, 2012

a survey carried out at time  $T$ . For a group of mothers subject to fertility rate of  $f(a)$ , we consider two subgroups of women - one group,  $H$ , who have a high level of mortality,  $m_H(a)$ , and another,  $L$ , who experience a low level of mortality,  $m_L(a)$ . As a result, the proportion of mothers that will produce offspring  $T - Q$  years before the survey will be lower for women who experienced the higher mortality rate,  $m_H(a)$ . As a result, individuals whose mothers experienced the lower mortality rate,  $m_L(a)$ , will be over-represented amongst respondents to the survey aged  $Q$ . Hence, the corresponding estimated conditional probability of survival,  $P(25 + T - Q|T - Q)$ , will be biased upwards and the estimated mortality levels associated with these conditional probabilities will be affected by increasing positive biases as the age of respondent gets smaller. The effect of the selection bias is that respondents aged  $Q$  years old will have been born to women, who are  $T - Q$  years older, who are disproportionately drawn from  $L$ , the group with lower mortality. The proportion of non-orphans,  $S(a)$ , will thus be:

$$S(a) = \frac{\int_{\alpha}^{\beta} (n_H(a + T - Q) \frac{l_H(a + T)}{l_H(a + T - Q)} + n_L(a + T - Q) \frac{l_L(a + T)}{l_L(a + T - Q)}) da}{\int_{\alpha}^{\beta} f(a + T - Q)(n_H(a + T - Q) + n_L(a + T - Q)) da}$$

in which the survivorship curve associated with subpopulation  $L$  will be over-represented, since  $n_L(a + T - Q) > n_H(a + T - Q)$  and the estimate of  $\frac{l_H(a+T)}{l_H(a+T-Q)}$  will be upwardly bias. This bias will be largest when no mothers from population  $H$  survive to produce additional offspring, and then the magnitude of the bias in the conditional probability will apporximately be equal to the difference in the conditional probabilities of surviving for subpopulations  $L$  and  $H$ , ie:

$$\frac{\hat{l}(a + T)}{\hat{l}(a + T - Q)} = \frac{\hat{l}_L(a + T)}{\hat{l}_L(a + T - Q)} - \frac{\hat{l}_H(a + T)}{\hat{l}_H(a + T - Q)} \quad (5.26)$$

Hence the bigger the mortality differential between subpopulation  $H$  and  $L$ , then the larger the magnitude of the bias. As Campbell and Lee (2003, 1996, 2009) have noted, health and mortality differentials within the registered Liaoning population were relatively small. Thus, the overall effect of this selection effect is small for orphanhood estimates derived from the CMGPD-LN registers.

## Sibling Survival Method

If the risk of mortality varies with sibship size, the classical sibling-survival method will produce biased estimates. An overestimate will result if there is a positive association between sibship size and mortality, as larger sibships experiencing more favorable health and mortality conditions will be over-represented. Table 5.3 shows how the association between sibship size and mortality

	No. Dead Brothers										
	0	1	2	3	4	5	6	7	8	9	10
N(n)	666	548	267	102	61	21	10	4	0	0	1
D(n)	6,712	5,311	2,959	1,327	603	222	67	51	14	28	7
no. sibships	6,587	5,178	2,883	1,302	577	211	62	50	14	28	7
$PD_{real}$											.0992
$PD_{observed}$											.0921

Source: CMGPD-LN, 2012

Table 5.3: Reporting of Sibling-Survival Status in CMGPD-LN Registers, 1864

results in an under-estimation of adult mortality in 1864 using the CMGPD-LN registers.

In order to correct for selection bias, Gakidou and King (2006) and Masquelier (2013) have proposed re-weighting formulae. Gakidou and King (2006) propose a family-level weighting scheme -  $\frac{B_i}{S_i}$ , where  $B_i$  is the number of siblings born to parent  $i$  at the start of the period and  $S_i$  is the number of siblings that survive to the time of the data collection. Whereas as Masquelier (2013) proposes a sibship-level weighting scheme -  $\frac{1}{S_i}$ .

The motivation behind both of these weighting schemes is to re-weight estimates by down-weighting the sibships with high rates of survivorship. The classical sibling-survival method, as a means to estimating  ${}_{45}q_{15}$ , calculates the proportion dead in each sibship as follows:

$$PD = \frac{\sum_{x=0}^{n-1} x(n-x)f(x)}{\sum_{x=0}^{n-1} (n-1)(n-x)f(x)} \quad (5.27)$$

where  $x$  is the number of dead siblings,  $n$  the size of the sibship,  $(n-x)$  the number of respondents in each sibship,  $f(x)$  the probability mass function of the binomial distribution.

The weighting scheme proposed by Gakidou and King (2006) specifies an adjustment to the proportion dead as follows:

$$PD = \frac{\sum_{i=1}^m \frac{D_i}{B_i} \times \frac{B_i}{S_i}}{\sum_{i=1}^m \frac{B_i}{S_i}} \quad (5.28)$$

$$= \frac{\sum g(n) \sum_{x=0}^{n-1} x f(x)}{\sum g(n) \sum_{x=0}^{n-1} n f(x)} \quad (5.29)$$

where  $g(n)$  is the distribution of sibship sizes.

However, Masquelier (2013) has noted that Gakidou and King's weighting scheme operates at the family-level. However, the sibling-survival method operates at the sibling-level whereby the proportion dead are calculated from data organized by respondent in which each observation containing sibling histories per sibling. As a result, Masquelier (2013) proposed an alternative weighting-scheme that operates at the sibling-level whereby the the numerator and denominator for the proportion dead is weighted by the inverse of the number of surviving siblings:

$$PD = \frac{\sum_{i=1}^m \frac{D_i}{S_i}}{\sum_{i=1}^m \frac{B_i}{S_i}} \quad (5.30)$$

Given that sibship size and adult mortality are strongly negatively correlated in the CMGPD-LN registers ( $\rho = -0.721$ ), I adjusted for this association using both the family-level and sibling-level corrections. In Figure 5.7 and 5.8, I compare the resulting indirect sibling-survival estimates with both the uncorrected sibling survival estimates and the life-table estimates of  ${}_{45}q_{15}$ . Both adjustment procedures correct for the systematic under-estimation to which the unadjusted sibling-survival method is vulnerable. Masquelier (2013), in his examination of DHS data in which he observes little association between sibship size and mortality, notes that the family-based correction weights over-correct for survivorship bias but that the sibling-level correction weights don't over-correct. He notes that this is because such weighting-schemes are usually misapplied for all siblings instead of simply for adult siblings only. In the case of the CMGPD-LN registers, when both weighting schemes are applied to adult siblings, we see that they perform similarly and provide adjustments to the indirect sibling-survival method that considerably reduce the under-estimation of  ${}_{45}q_{15}$ . As shown in Table 5.2, the adjusted sibling-survival estimates fall within the 95% confidence intervals for around 65-69% of the point estimates - considerable improvement over the unadjusted sibling-survival estimates.

## Death Distribution Methods

In contemporary settings, death distribution methods are most commonly applied when there are two national population censuses and available death registration data. Given that most countries undertake a national population census every 10 years, the examination of the GGB and SEG methods using triennial censuses may be unrealistic. Figure 5.2 presents some sensitivity test results in which GGB and SEG estimates were re-estimates using 6, 9 and 12 year interval spans between census rounds. Given the completeness of these CMGPD-LN registers we observe very little difference between GGB and SEG estimates derived using 3-year spans and long spans. The variability of GGB and SEG estimates with larger spans are very similar to those derived using 3-

year spans. Similarly, when applying GGB and SEG estimates with larger spans, the magnitude of bias associated with these estimates is comparable to that associated with estimates derived using 3-year spans. Hence, the use of somewhat non-traditional 3-year durations in between censuses does not appear to have had a substantial effect on the evaluation of death distribution methods against orphanhood and sibling-survival methods.

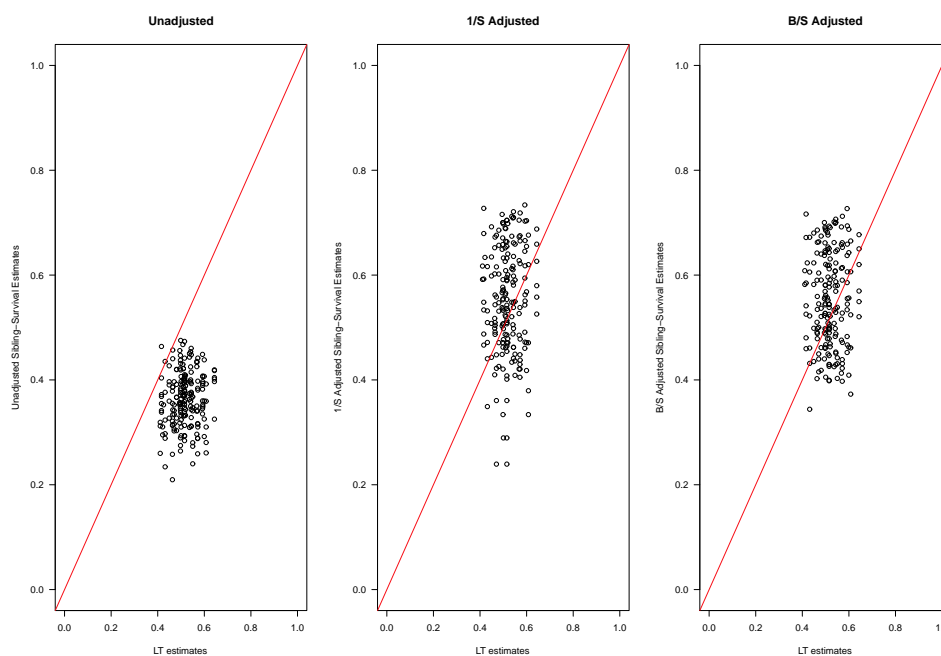


Figure 5.7: Comparison of Adjusted/Unadjusted Sibling-Survival Estimates with Life Table Estimates

## 5.8 Conclusions

Given the paucity of high quality civil registration systems in many low-income countries, it remains challenging for demographers to accurately estimate adult mortality rates for these populations. As a result, heavy reliance has been placed on adult mortality estimation methods that draw on data from household surveys and population censuses. Further, recently there has been renewed interest in the development and refinement of adult mortality estimation methods when high quality civil registration is lacking. Although these methods have been widely applied over the last three decades, particularly in sub-Saharan Africa and Asia, there has only been limited

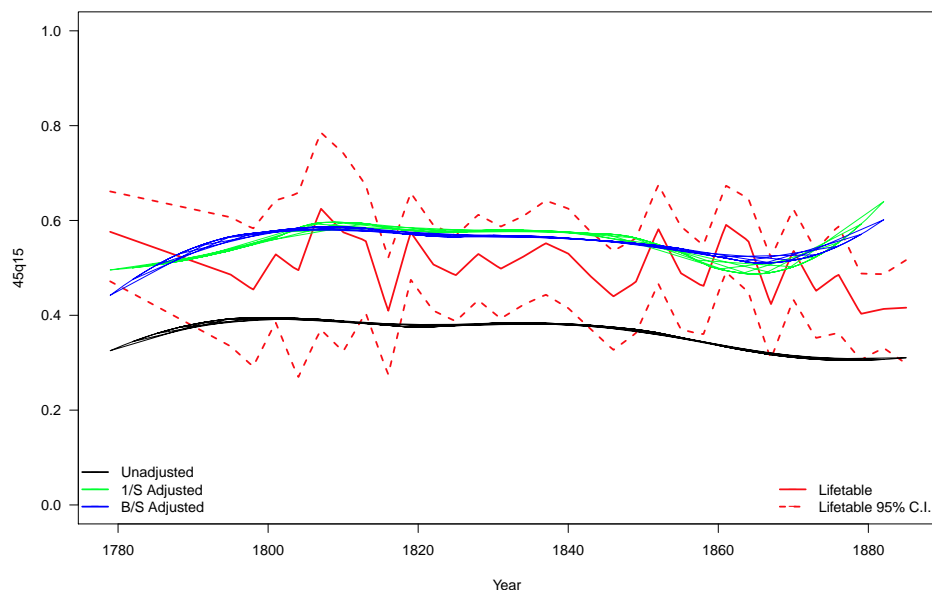


Figure 5.8: Temporal Pattern of Adjusted and Unadjusted Sibling-Survival Estimates and Life Table Estimates

assessment of the reliability and validity of these indirect methods. Most assessments of indirect adult mortality estimation methods have focused on the effects of reporting errors on the reliability of resulting estimates. Further, I know of no previous study that has comparatively examined the reliability and precision of death distribution methods with indirect kin-based estimation methods.

In this chapter, I focused on the simplifying assumptions of indirect methods and explored the validity of two main classes of indirect adult mortality estimation methods: kin survivorship-based methods and death distribution methods. By drawing on high quality triennial population registers from Liaoning, China, I was able to examine the performance of these methods in estimating the probability of dying between ages 15 and 60,  ${}_{45}q_{15}$ , against life table estimates. In particular, I was able to use internally consistent data and thus focus on issues of bias and variability of the different indirect estimation methods. I found that the kin-based estimation methods, namely the orphanhood method and sibling-survival method (after adjustments are made for survivorship bias) were the more consistent with life table estimates than death distribution methods.

I find that the unadjusted orphanhood estimates are the most consistent with life table estimates of  ${}_{45}q_{15}$ . However, as other authors have noted, the nature of orphanhood data is such that they refer to periods prior to the data collection period about 10-15 years earlier than analogous

sibling-survival and death distribution data. Though, by adjusting sibling-survival data for survivorship bias the performance of the sibling-survival method can be considerably improved – although such adjustments appear to over-adjust.

However, this analysis is vulnerable to a number of limitations and complications. For Liaoning, censuses are triennial so there remains a small amount of uncertainty around the exact time location of vital events (ie Liaoning is only a quasi validation dataset). Given that the CMGPD-LN registers are collected every three years, they demonstrate a notably higher level of data quality than is normally present in contemporary population censuses and household surveys. Further, there may be questions about the appropriateness of using contemporary model life table approximations for historical Northeast Chinese populations. The applicability of validation results from the CMGPD-LN registers may not be directly transferable to contemporary developing country contexts given that the demography of Liaoning differs notably from many developing country contexts. For one, the challenges associated with measurement of adult mortality in the presence of high HIV-prevalence is not something that is reflected in the CMGPD-LN registers.

Nevertheless, the somewhat stylized nature of the CGMPD-LN registers provide a useful means by which to explore the comparative performance of indirect adult mortality estimation methods and thus stimulate policy and practice on how to best measure adult mortality while continuing to develop civil registration systems. The results in this chapter suggest that kin-based survival data collected regularly (eg triennially) are an effective low-cost method to measure adult mortality when comprehensive civil registration systems are lacking. Despite the limitations of indirect methods, indirect methods provide a solid basis for the construction of full life tables. Further, they are efficient in that each data collection round provides estimates of the historical trend in adult mortality, whereas direct estimation methods are only able to provide estimates for a single point in time. Thus, given the need for interim cost-effective methods to monitor adult health and mortality, indirect estimation methods offer an efficient and cost-effective complement to direct estimation methods.



## Chapter 6

# Assessing the Quality of Mortality Data from Demographic Surveillance: A Case Study from Agincourt, South Africa

### 6.1 Introduction

Over the last few decades, there has been an increasing demand for health data and mortality measurement from policy-makers and practitioners to help assess program efforts against development goals. These health and development goals, while aspirational, have been articulated within a framework of benchmarks (for reduction in mortality rates, in the cases of Millennium Development Goals (MDGs) 4 and 5) that are time-specific. However, demographers and statisticians have increasingly noted the paucity of high quality data to accurately evaluate development progress and, in particular, progress towards the MDGs.

As discussed by Setel et al. (2007) and in Chapter 2 of this dissertation, advances in the coverage and quality of civil registration systems in the post-WWII have been limited. To date, in low-income countries, the response to these demands for more data and better measurement have primarily been organized around sources such as population censuses and household surveys and associated measurement methods. As Sanga (2011) has noted, this response - particularly in sub-Saharan Africa - has achieved some important milestones (such as better documentation of the standards and methods used to compile and analyze MDG indicators as well as increased technical cooperation to address problems of comparability of data across sources and countries) but has been constrained by notable structural limitations. These limitations include considerable gaps in data and sometimes a disproportionate focus on monitoring of health and development progress (particularly with the MDGs) at the global and regional level instead of the national and subnational level. In China and India, there has been substantial investment in sample registration systems as

a means to improve the evidentiary basis for mortality and health evaluations. However, these efforts, while complementary to survey-based and census-based approaches, involve challenging sampling issues and substantial costs both in terms of initial set-up and maintenance of continuous operations (Setel et al., 2006; Rao et al., 2005).<sup>1</sup>

Bangha et al. (2010), recognizing the limitations of population censuses and household surveys in assessing health and development progress, have emphasized the strengths of demographic surveillance sites (DSS). DSS sites are organized around regular and repeated censuses of a geographically defined population and entail the systematic recording of vital events (births, deaths and in/out migration). Bangha et al. (2010) noted, in particular, the longitudinal nature of demographic surveillance and the associated rigor in which DSS data are collected and managed. High quality mortality data, such as DSS data, has also played an important role in advancing our understanding of mortality transitions and developing empirically-based mortality models (Heuveline and Clark, 2011), as well as shaping our understanding of how mortality transitions impact primary healthcare systems (Tollman et al., 2008). The strengths of such DSS data, after much lively debate (Chandramohan et al., 2008) and important technical advances in the form of INDEPTH's iShare platform,<sup>2</sup> recently became more widely available for population and health science research (Sankoh and Byass, 2012; Sankoh et al., 2013).

The purpose of this chapter is to develop a framework for the data quality assessment of mortality data collected from subnational demographic surveillance sites. Such a framework is intended to enhance comparisons along different dimensions - for example (i) the comparison of mortality data quality from a single DSS site across different years, (ii) the comparison of mortality data quality from multiple DSS sites, and (iii) comparison of data quality at DSS sites with mortality data from other sources, such as the Human Mortality Database (HMD). This case study builds on previous work by INDEPTH scientists in assessing the quality of DSS data and the data quality assessment work of HMD researchers associated with official mortality data at the national level.

## 6.2 Background & Motivation

Infant and child mortality, adult mortality and life expectancy are all important indicators of health and development progress (Sen, 1995; Preston, 1975, 2007). Yet, in developing countries, there are a number of important methodological challenges associated with the measurement of

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<sup>1</sup>It should be noted, though, that some recently launched demographic surveillance sites have started to explore low-cost methods of surveillance. For example, in Northern Malawi researchers have found that village-informant demographic surveillance that is customized to the local context can produce relatively complete and high quality basic vital registration data (Jahn et al., 2007). However, earlier work in Burkina Faso at the Oubritenga DSS site suggested otherwise, perhaps pointing to the importance for customization of data collection procedures to the local context (Diallo et al., 1996).

<sup>2</sup>See [www.indepth-ishare.org](http://www.indepth-ishare.org).

these demographic indicators which remain unresolved or poorly understood. At the heart of these challenges are (i) the diagnostic assessment of error and bias in underlying mortality data, (ii) the modeling of these errors and biases to quantify measurement uncertainty, and (iii) the study of model uncertainty which arises from the approximation inherent in applicable demographic estimation techniques.

The lack of complete vital registration in developing countries has hampered accurate knowledge of mortality levels and trends (Mahapatra et al., 2007a). In order to derive most summary measures of mortality (such as life expectancy), a comprehensive set of age-specific mortality rates are required. As a result, demographers have placed heavy reliance on data from decennial censuses, retrospective mortality surveys (such as the Demographic and Health Survey (DHS) system and UNICEF's Multiple Indicator Cluster Survey (MICS) program) and models underpinned by model life table systems (most notably the Coale-Demeny and United Nations model life table systems). Yet these data are often hampered by a number of limitations - most notably non-sampling errors in the form of recall errors, survivorship biases, and misreporting errors - that have been discussed in Chapters 3 and 4 of this dissertation. Further, model life table patterns are heavily dependent on historical European patterns, which may not be representative of age patterns of mortality in contemporary developing country populations, and do not reflect recent phenomena such as HIV/AIDS-related mortality. Thus current empirical estimates of mortality in developing countries are subject to considerable uncertainty and measurement error. Further, mortality analyses on developing country survey data, which draw on the classical direct and indirect estimation methods, often do not adequately account for the strong model assumptions and quantify common errors and biases (such as recall error, survivorship bias, etc.).

Demographic surveillance site data are a valuable data source in developing countries, which have not been fully utilized by demographers (Pison, 2005; Baiden et al., 2006). These data mimic the richness and quality of complete vital registration data, but are geographically focused on documenting the vital events of small subnational populations. The sites usually cover between 10,000 and 20,000 households. Most of the 60 or so DSS sites around the world are coordinated by the International Network of field sites with continuous Demographic Evaluation of Populations and Their Health in developing countries (INDEPTH).<sup>3</sup> Currently, within the INDEPTH Network, there are 44 DSS sites in 20 countries in Africa, Asia, and Oceania which register vital events approximately 2.83 million persons.

Demographic surveillance has a long and rich history around the world. The earliest forms of demographic surveillance, which usually took the form of parish registries or local population registers, date back several centuries. The earliest known population register is from the Han Dynasty period in China (and modern-day Taiwan) during the second century B.C (Bielenstein, 1980). In

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<sup>3</sup>[www.indepth-network.org](http://www.indepth-network.org)

Japan, population registration dates back at least to Taika restoration period in the seventh century A.D (Farris, 1995). The oldest preserved parish registers in Europe are from England, France and Italy and date back to the mid-1500s (Wrigley and Schofield, 1989; Gautier and Henry, 1958; Goubert, 1960; Alfani, 2006). These registers have their origins in official Church decrees and local clergy's practice of maintaining records of religious and secular officials. Such record keeping was subsequently expanded to the local population. By contrast, in more recent times, localized population registration and surveillance has been motivated more by evidence-based public health initiatives. For example, one of the earliest forms of modern demographic surveillance was developed in China in 1932 in Dingxian district, which encompassed 103,087 residents in the surveillance area (Chen and Bunge, 1989). Further the world's longest-running DSS site, established in Matlab, Bangladesh in 1963, was originally founded to test the effectiveness of cholera vaccine programs and has subsequently expanded considerably in its size and scope (Aziz and Mosley, 1997).

Garenne et al. (1997), in reviewing the evolution of demographic surveillance data resulting from prospective community studies, have noted that although the focus of many of these DSS sites was originally family planning, there has been a consistent shift in their focus towards the study of health and disease processes. Tollman et al. (1997) have noted that such studies, in the tradition of public health approaches, take the community as the object of study, as opposed to clinical studies that focus on the individual.

The operational and technical challenges involved in the collection and storage of DSS data are non-trivial. Data collection and systematic documentation practices can be particularly challenging in rural areas in low-income countries - where electricity can be intermittent, telecommunications systems unreliable and transportation infrastructure often underdeveloped. Further, the longitudinal nature of the data require sophisticated data management practices, the living arrangements of the resident population can be diverse, and the registration of migration events is labor intensive Berhane et al. (1999). Yet, these DSS data are likely to be the highest quality mortality data available for most countries in sub-Saharan Africa. Clark (2004) has profiled their notable strengths, noting that:

- DSS data usually describe populations that are not described by other data,
- they are individual-based, prospectively collected, fully linked data describing whole populations at several levels, and
- they are longitudinal and often describe the long term history of the population under study.

However, DSS data do suffer from limitations including issues of (national) representativeness and the relatively high cost in maintaining a DSS site.

Madhavan et al. (2007), in their detailed review of the Agincourt Demographic Surveillance System in South Africa, noted that the quality of DSS data are dependent on the local community's continued acceptance of the DSS's objectives and the community's involvement in the process. In particular, they argue that the long-term presence of the DSS and its community involvement contribute to high response rates and improved data quality, the continuous reporting back to community members provides valuable checks on the local relevance and comprehension of questions, and coordinated community feedback can help customize both wording and the content of research questions. Thus, the underlying design and implementation process of demographic surveillance are fundamental in ensuring high quality health and mortality data.

The founding of the INDEPTH Network in 1998 has helped facilitate the sharing of lessons learned on operational fieldwork issues as well as collaborations around methodological research and substantive insights (INDEPTH Network, 1998). A key motivation for this chapter is to draw on these important advancements and contribute to the evaluation of DSS data quality assessment by integrating recent advances from the Human Mortality Database (HMD) project. The HMD was developed to document the longevity revolution of the modern era and to facilitate research into its causes and consequences.<sup>4</sup> The technical work of the HMD has been underpinned by the guiding technical principles of comparability, flexibility, accessibility, and reproducibility. This underlying rigor and meticulous evaluation of data quality has underpinned a wide range of research publications on the nature of and variation in mortality transitions and population ageing processes across several national populations (Human Mortality Database, 2008). As more DSS sites are set up (Aryal et al., 2012; Tran et al., 2012), and data from INDEPTH DSS sites becomes more widely accessible, the demand for comparative analyses (both between different DSS populations and of a given population using complementary data sources) is likely to grow. This chapter seeks to contribute to an increasingly robust platform for such comparative analysis.

## 6.3 Literature Review

Bobadilla et al. (1997), in their study of mortality transitions in the newly independent states of the former Soviet Union, have noted the importance of transparency in reporting underlying data quality and the use of adjustment methods to calculate life tables and summary demographic statistics. They note, in particular, that both policy-makers and researchers need “to be aware that overall measures of mortality, such as expectation of life at birth and expectation of remaining life at all ages, may be substantially affected by the methods used in the construction of life tables.”

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<sup>4</sup>The Human Mortality Database (HMD) consists of high-quality life tables for national populations of industrialized countries and thus represents high-quality vital registration. The earliest year for which data are available is 1751 (for Sweden), and the most recent year for each country is around 2010.

Demographers often evaluate data quality along two primary dimensions: coverage and content. Coverage refers to the level of inclusion into the data system of people or demographic events in the reference population or study area. Hence, coverage errors refer to under-registration or over-registration of individuals and events in the study area. Content errors refer to inaccuracies in the recording of basic details and relevant covariates associated with individuals and events.

In the sections below, I provide a brief overview of methods for identification of coverage and contents errors and also review demographic analysis methods that have been used in data quality assessments of mortality data.

### **Methods to Identify Coverage Errors**

Coverage analysis has been carried out by collecting a re-interview sample (usually via a post-enumeration survey), matching the sample at the record-level to the DSS enumeration and, and then using dual-systems estimation to estimate the size of the unenumerated population (Sekar and Deming, 1949).

This evaluation can be expensive and time-consuming, as an independent data collection effort is required in addition to intensive record-level matching. Further, dual systems estimation makes the strong assumption that the probability of an individual/event being enumerated in the first data system is independent of being enumerated in the second data system (Freedman and Wachter, 1994). Nevertheless, dual systems estimation has played an important role in identifying and adjusting for under-registration of minority populations and duplicate registration of other sub-populations in the decennial censuses of the United States (Prewitt, 2000; Zaslavsky, 1993; Bell and Cohen, 2008). Recently official statisticians in the United States have shifted their motivation and focus of coverage analysis and evaluations that use dual systems estimation. Less emphasis is being placed on the adjustment of census counts and, instead, more focus is being given to the use of post-enumeration survey data evaluations to inform the improvement of census field operations and processes (Bell and Cohen, 2008).

### **Methods to Identify Content Errors**

Given the importance of age structure in the estimation of mortality (and fertility), demographic data quality assessment has mostly focused on reporting of age information. Such age misreporting can be borne out of respondents' ignorance, interviewer bias, and data processing errors. Ewbank (1981) has noted that there are four main approaches to the identification of age reporting errors: (i) record-level matching comparisons of age reporting in two independent data sources (eg a population census and a post-enumeration survey), (ii) internal comparison methods to examine the age distributions of various groups in a population to identify signs of unexpected differences in

their characteristics (for example, sex-based comparisons of age distributions), (iii) external comparison of age reporting of the same population from different data collection exercises, and (iv) diagnostic indices (such as Whipple's Index and Meyers Blended Index) to identify evidence of age heaping.

Despite their considerable expense, record-level matching studies only provide a measure of the variance in the age reporting error. But as Preston et al. (1996) have shown, by matching a sample of death certificates for elderly African Americans to three successive census enumerations in the United States, the direction of bias in age reporting at the individual level is unexpectedly different to what is observed for the aggregate measure. A limitation of internal comparison tests, such as sex-ratio tests for age misreporting, is that they cannot distinguish between deviations due to age misstatement and deviations due to sex-selective misreporting.

Diagnostic data quality indices are primarily used to identify age exaggeration and age heaping in raw mortality data. Age heaping refers to the extent to which age data show systematic heaping on certain ages as a result of digit preference or rounding. The most commonly observed heaping patterns are observed for ages ending in 0 and 5. Whipple's index and Myer's blended index are the two most widely used measures for age heaping (Swanson et al., 2004). The classical Whipple's index has been widely used to test for age heaping on ages ending in 0 and 5, whereas Myer's index offers more versatility (with slightly more complicated formulae) in its ability to identify preferences for any terminal digit. Age exaggeration is most commonly measured by examination of the ratio of deaths at ages 105+ and ages 100+ (Jdanov et al., 2008).

In addition to these techniques of identifying age misreporting, Bourgeois-Pichat (1946) has outlined a model for assessing potential problems with birth and child mortality data. His model decomposes infant mortality into an endogenous or underlying component and an exogenous component that indicates mortality due to environmental factors. This model fits the cumulative proportion dead,  $q(n)$ , in a cohort by age  $n$  days between the end of the first month and the end of the first year of life, as follows:

$$q(n) = a + b[\log(n+)]^3 \quad (6.1)$$

where  $a$  represents the endogenous mortality component. Thus the Bourgeois-Pichat model provides a useful benchmark against which to assess the quality of birth and infant death registration.

## Previous Work on Assessing Data Quality of Subnational Demographic Surveillance Data

There are two main types of data quality assessment that are carried out at most demographic surveillance sites: (i) in-field assessments and (ii) post-fieldwork assessments.

In-field assessments include field-based supervision of enumerators, reviews of completed survey forms, and a re-interview process of a select subsample of approximately 3-10% of the households (INDEPTH Network, 2002). Post-fieldwork assessments include both database integrity assessments as well as demographic/statistical analysis.

Post-fieldwork data integrity assessments are focused on exploiting the relational structure of DSS data to identify illogical values, invalid codes, duplicate entries, and items with missing values. Such data integrity assessments are underpinned by well-defined relational data models (Benzler et al., 1998; Clark, 2006).

The demographic and statistical evaluations of DSS data quality have focused both on coverage analysis and plausibility of the age-sex reporting of the population. Recently, coverage analysis has been carried out using record-linkage techniques in Bandafassi, Senegal to evaluate the reliability and validity of maternal mortality and female adult mortality data collected at a DSS. Helleringer et al. (2013a), when assessing maternal mortality reporting, considered the DSS data as a 'gold standard.' They found that 94% of deaths classified as pregnancy related in the DSS data were also so classified in independently-collected sibling survival histories. When assessing overall adult mortality reporting, Helleringer et al. (2013b), using capture-recapture methods, found that the DSS was able to capture 89.8% of all deaths: 96.3% of adult female deaths were documented by the DSS, whereas only 73.6% of female deaths under 15 years of age were documented by the DSS. These results suggest that DSS processes are more effective in documenting adult deaths than child and adolescent deaths and are consistent with earlier evaluations at other DSS sites (Becker and Mahmud, 1984; Pison and Langaney, 1988). Collinson et al. (2007), by triangulating health and demographic surveillance with national census data, found that DSS data were much more effective in capturing temporary and circular migration events of the highly mobile and rural population studied at the Agincourt DSS – suggesting that such data systems are less vulnerable to 'errors of closure.' Fotterell et al. (2008) have, using data from Ethiopia, evaluated the impact of random errors in DSS data on the estimation of demographic parameters. They found that the effect of such random errors on the population age-sex distribution was minimal and that mortality risk factors were largely unaffected even by relatively high levels of random errors in the data.

## 6.4 Description of Data & Methods

### Overview of Agincourt Site and Data

The Agincourt DSS field-site,<sup>5</sup> which was set up in 1992, is situated about 300 miles north-east of Johannesburg in the Agincourt sub-district of Bushbuckridge region, of the Northern Province

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<sup>5</sup>For a detailed overview the Agincourt Demographic Surveillance Site as well as its data collection and data management processes, see Kahn et al. (2007).



in South Africa. Until 1994 the site was located within a Bantustan (homelands) area. The field site spans twenty-one village communities across an area of 250 square miles. Approximately one-third of the residents in the DSS area are of Mozambican origin – a substantial portion arrived in the mid-1980s during the Mozambican civil war. Given the proximity of the site to the Mozambican border and the high unemployment in the area, temporary migration is common.

As of 2010, the total surveillance population was 66,840 people living in 10,500 households, with a population density of around 300 persons per square mile. The sex ratio for the total population is 929 males per 1,000 females and the study population is characterized by a young population age structure. As shown in Figure 6.1, the age-sex distribution for this population has a classic pyramid-like shape for countries in sub-Saharan Africa: the population is characterized by high fertility, relatively low life-expectancy, and a high youth dependency ratio. The setting is rural in terms of distance from urban centres and lack of infrastructure. The main ethnic group is Shangaan, although Mozambicans, originally refugees, comprise more than a quarter (29%) of the total population. Both groups are Shangaan-speaking and the Mozambicans are culturally affiliated to the South African host population. The steady flow of in-migration into the DSA area is shown in Figure 6.2. There are mainstream Christian churches, independent African churches and an amalgamation of traditional and Christian beliefs are often practiced.

Figure 6.3 showcases the diversity of residential patterns in the Agincourt DSS by displaying six different stylized life-course patterns. Each diagonal line represents the observed lifecourse trajectory for an individual person while resident in the Agincourt DSA area. Black circles represent birth and death events observed in the DSA area, whereas yellow circles represent in/out-migration events. These six life lines show an array of residential histories for native-born residents (individuals C and E), as well as migrants (individuals A, D, E and F), survival trajectories (deaths during the observation period of individuals A, B and E), and temporary migration events (individuals D and E).

The Agincourt DSS site was established with a comprehensive baseline survey in 1992 in which all births, deaths and migration events since then. Subsequently this census was updated every 15-18 months between 1993 and 1999, and from 1999 census updates have been carried on an annual basis. The data collected at the Agincourt DSS, as with all DSS sites, are truly longitudinal and recorded as events and episodes in relational databases (Clark, 2006). To calculate mortality rates, we need data that locate vital events in time and clearly document the persons years in which an individual is exposed to the risk of dying in the Agincourt DSA. Table 6.1 displays the basic data structure we use to identify vital events and derive basic exposure times for each resident of the

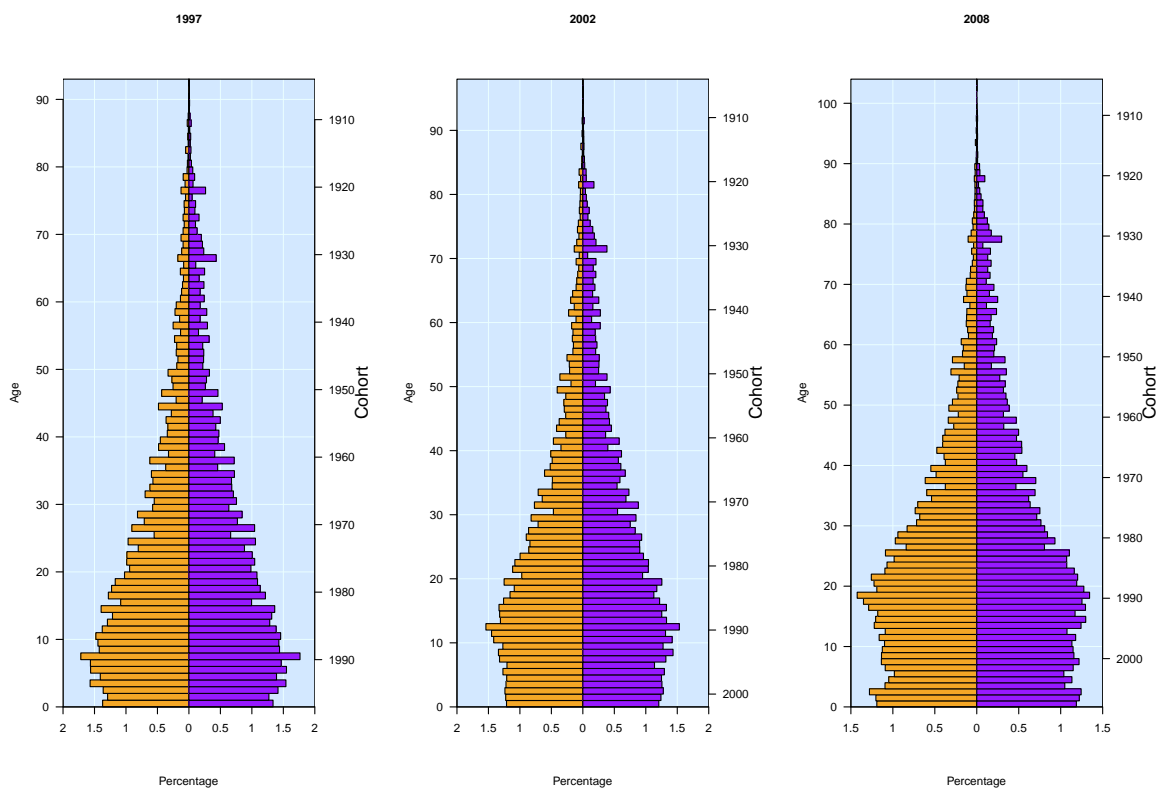


Figure 6.1: Agincourt DSS Population Structure by Age and Sex, 1997-2008

DSS area.

When an individual is born while their mother is resident in the DSS area, their birth corresponds to the start date for their first exposure interval. If the date of birth is equal to the exposure start date of one of the individual's exposed intervals, then the birth is assumed to have occurred within the DSA while the mother was under observation and it is included in any counts of births. Correspondingly if an individual's date of birth does not equal the exposure start date of any of the individual's observed exposed intervals, then it is assumed that the birth was not observed and it is not included in any counts of births. When a resident individual dies inside the DSS area, their date of death corresponds to the stop date for their last exposure interval. If the date of death does not equal the exposure stop date of any of the individual's observed exposed intervals, then it is assumed that the death occurred outside the DSS area or during a period when the individual was not properly under observation, and as a result the death is not included in the death count.

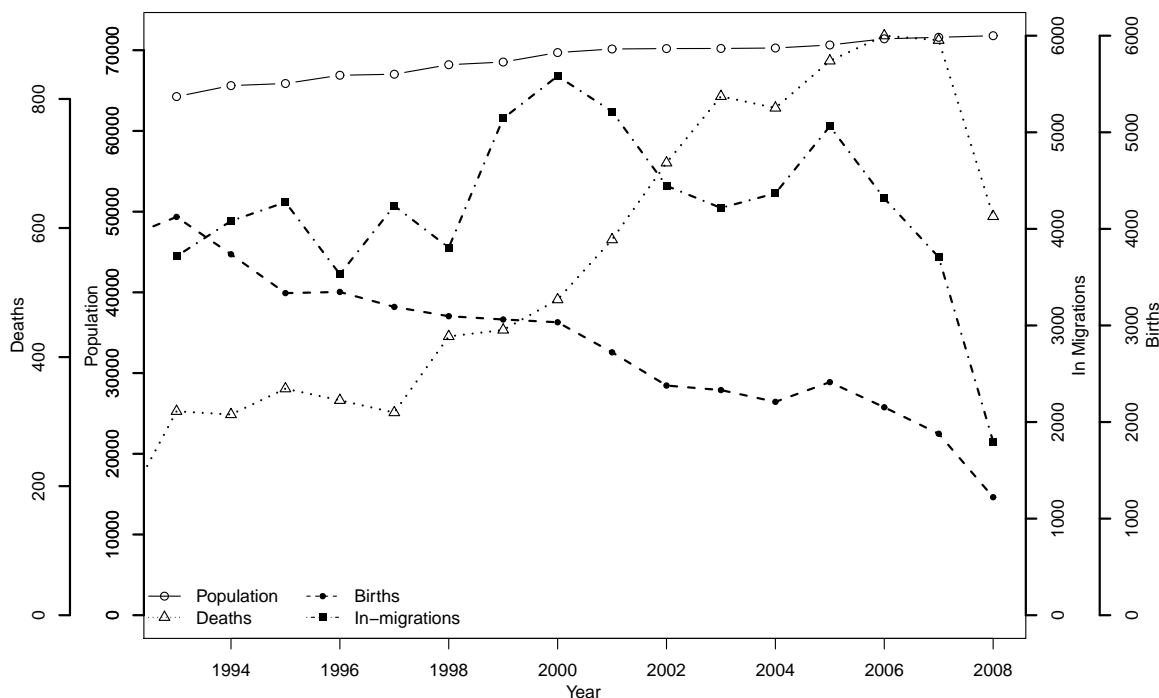


Figure 6.2: Counts of Population size, Births, Deaths, and In-Migrations by Year, 1993-2008

## 6.5 Data Quality Assessment

To assess the quality of mortality data from the Agincourt DSS, I carry out a series of internal and external assessments of the data. Internal assessments are evaluations of the data for internal consistency or checks for unexpected and/or implausible demographic patterns. External assessments are evaluations of the data against external data sources that are thought to be high quality and subject to only minimal errors in the underlying raw data. In my external assessments, I use data from the Human Mortality Database.

### Internal Assessments

#### Sex Ratios of Births & Deaths

The sex ratio of reported births and deaths is an important demographic indicator and a useful data quality metric for demographic data. Figure 6.4 displays the reported sex ratios at birth and death in the Agincourt DSS data. We observe that the sex ratio of retrospectively reported deaths

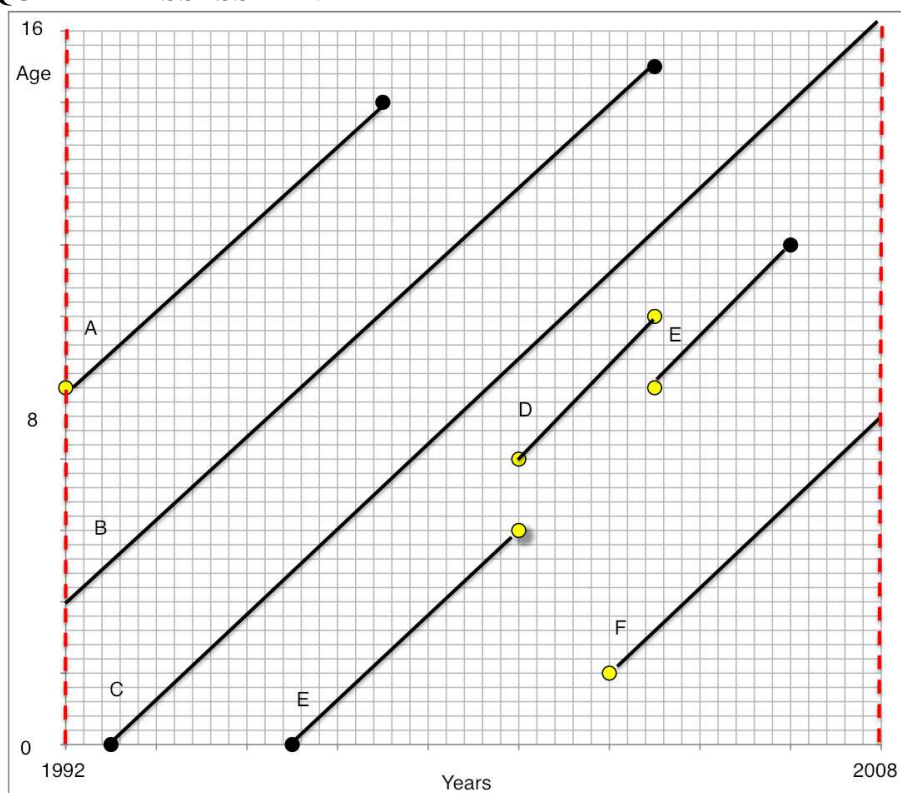


Figure 6.3: Lexis Representation of Diversity of Residency Patterns Observed in Agincourt DSS, 1992-2008. Individual A migrates into the area at age 9, and lives in the area until death at age 14; Individual B is observed in the 1992 baseline census at age 4 and resides in the area continuously until death at age 15, individual C is born in 1993 in the DSA area and is observed continuously in each subsequent census round, individual D is a temporary migrant who enters the site at age 7 in 2002 at leaves the area two years later, individual E is born in 1997 in the DSA area, migrates out of the area in 2002 and returns in 2005 before dying in 2006, individual F migrates into the area in 2004 and is observed continuously until the last census round in 2008.

(ie deaths occurring before the launch of the demographic surveillance site) are heavily skewed towards women. In contrast, births recorded in near real-time (ie those occurring after 1992) are much closer to 1.0 - suggesting that the real-time recording of births is much more consistent and complete across the sexes. The sex ratio for deaths, recorded between 1993 and 2008, are subject to much more variability than those for births and indicate that generally 5-40% more deaths of males are documented each year than for females.

No.	Field Name	Data Format	Null Values
1.	Individual ID	Unique Alphanumeric String	No null values
2.	Sex	Male/Female/Unknown	No null values
3.	Date of Birth	MM-DD-YY	No null values
4.	Date of Death	MM-DD-YY	Null values allowed
5.	Date of Exposure Start	MM-DD-YY	No null values
6.	Date of Exposure End	MM-DD-YY	No null values

Table 6.1: Data Structure &amp; Format of Exposure Data from Agincourt DSS, 1992-2008

### Age Heaping

Raw population data are often characterized by age heaping, in which individuals tend not to give their exact age but instead they round their age up or down to the nearest number that ends in 0 or 5. When the ages are plotted, the age distribution isn't smooth and instead exhibits high concentrations of individuals with ages in ending in 0 or 5. Whipple's Index is a widely used measure to assess heaping on terminal digits ending in 0 and 5 (Swanson et al., 2004) and is defined as follows:

$$W = \frac{5 \times (P_{25} + P_{30} + P_{35} + \dots + P_{60})}{(P_{23} + P_{24} + \dots + P_{61} + P_{62})} \quad (6.2)$$

where  $P_x$  is the count of people (or deaths) at age  $x$  in completed years.

The classic Whipple's index only measures preferences for (or avoidance of) ages ending in either 0 or 5 without distinction. An extension of the Whipple's index was developed in Spoorenberg (2007), called the digit-specific modified Whipple Index, in which digit specific indices were developed to evaluate potential preference for (or avoidance of) ages ending in digits 0 to 9. The digit-specific modified Whipple Index is defined as:

$$W_i = \begin{cases} \frac{5 \times (P_{3i} + P_{4i} + P_{5i} + P_{6i} + P_{7i})}{5P_{3i-2} + 5P_{4i-2} + 5P_{5i-2} + 5P_{6i-2} + 5P_{7i-2}} & \text{for } i \in (1,2) \\ \frac{5 \times (P_{2i} + P_{3i} + P_{4i} + P_{5i} + P_{6i})}{5P_{2i-2} + 5P_{3i-2} + 5P_{4i-2} + 5P_{5i-2} + 5P_{6i-2}} & \text{for } i \in (3,9) \end{cases}$$

where  $P_x$  is the count of people (or deaths) at age  $x$  in completed years and  ${}_5P_x$  is the population (or number of deaths) in the age range  $(x, x + 4)$ .

If there is no digit preference or digit avoidance, the digit-specific modified Whipple index will be equal to 1, whereas an index above indicates digit preference and an index below indicates digit avoidance. Figure 6.5 shows the digit-specific modified Whipple index for male and female deaths documented in the Agincourt DSS between 1993 and 2008. We observe greater deviation in the

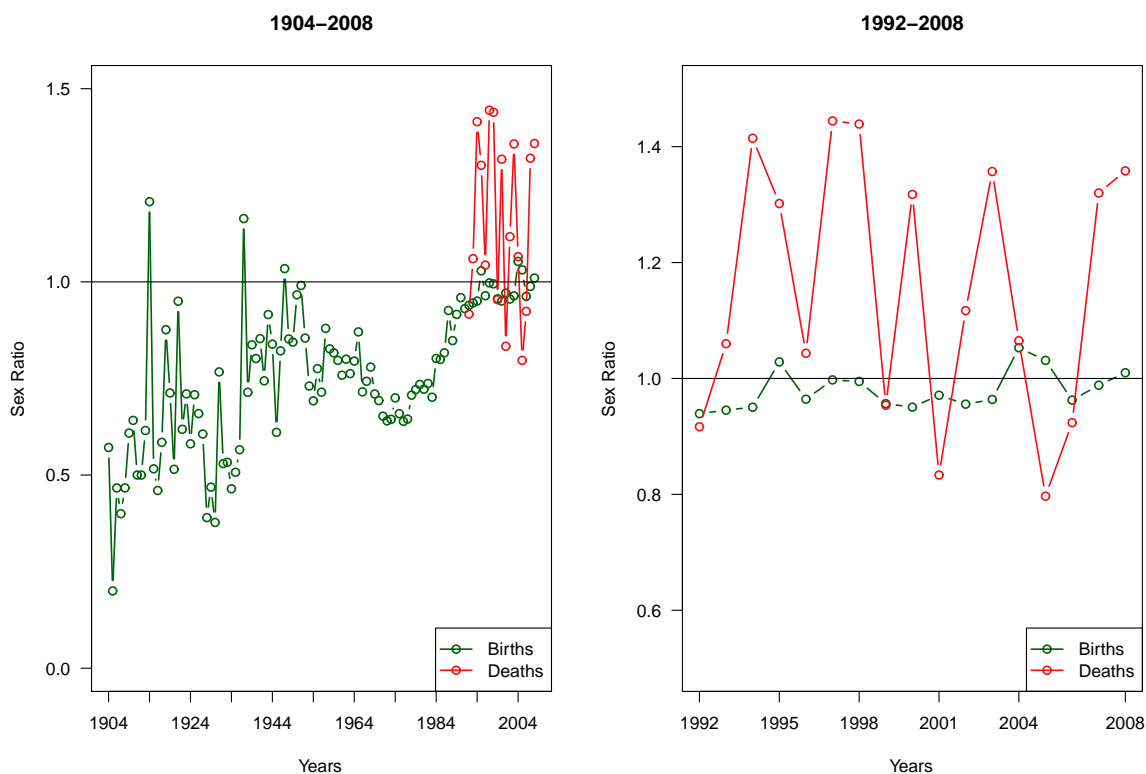


Figure 6.4: Sex Ratio (Male:Female) at for Registered Births & Deaths, 1904-2008

Whipple indices for female age at death reporting than for males. We also observe that there is no clear digit preference for ages at death ending in 0 or 5, unlike what is observed in population censuses from low-income countries such as India (where  $W_0$ ,  $W_5$  are usually greater than 2.5) (Spoorenberg, 2007). Although we do observe non-negligible deviation from the horizontal line at  $W_i = 1.0$ , to a similar degree to what is observed in population censuses of middle income countries like Morocco (Spoorenberg, 2007). Deviation of the modified digit-specific Whipple's Index from 1.0 to this degree is likely partly a function of the quality of age reporting and the stochastic variation in ages at death that may be observed in small subnational populations.

### Age Exaggeration

Age exaggeration, where respondents tend to overstate their age by reporting birth dates that are likely to be earlier than their actual dates of birth, is a common problem in demographic inquiries – particularly amongst the oldest old. Demographers, when assessing mortality data, often

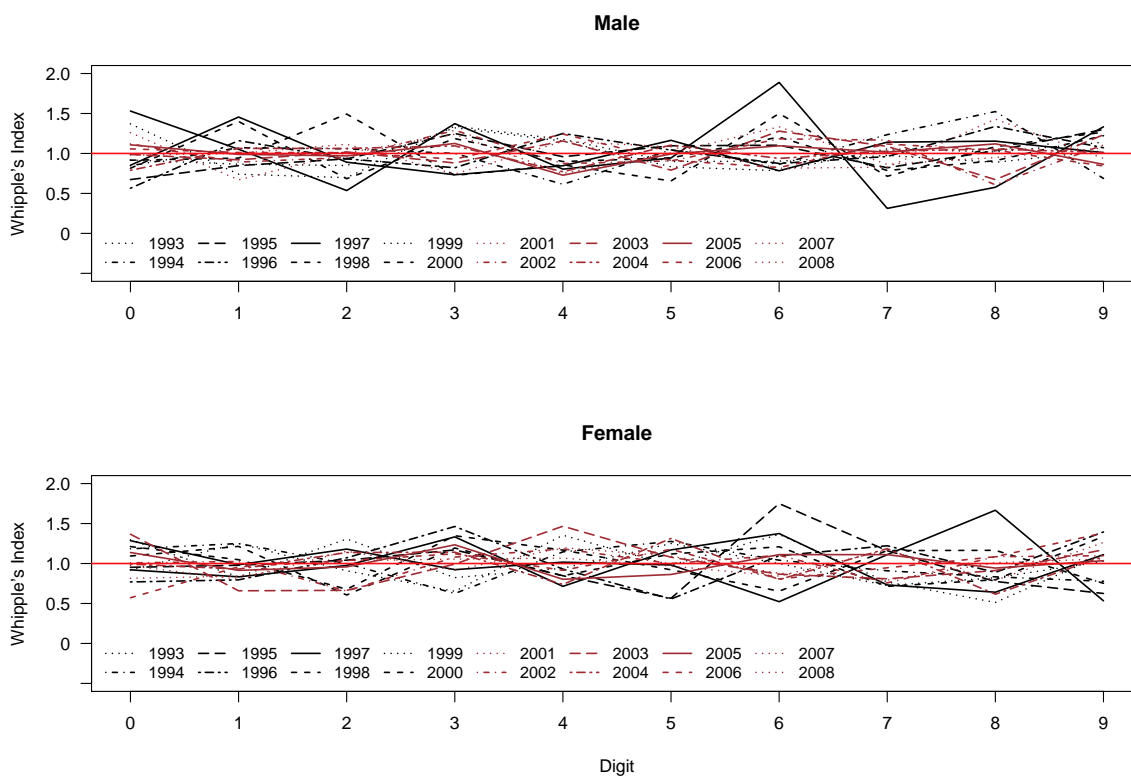


Figure 6.5: Digit-specific Modified Whipple's Index for Males and Females, 1993-2008

evaluate ratios of reported deaths above particular age to identify potential age exaggeration. Common ratios that are sometimes examined include  $\frac{D_{105+}}{D_{100+}}$ ,  $\frac{D_{105+}}{D_{90+}}$ , and  $\frac{D_{90+}}{D_{75+}}$ , where  $D_{x+}$  is the number of deaths reported in a given year above age  $x$ . When  $\frac{D_{x+}}{D_{y+}} > 0.2$ , the data are deemed to exhibit severe age exaggeration and when  $\frac{D_{x+}}{D_{y+}}$  falls between .15 and .199, the data are deemed to exhibit substantial age exaggeration (Jdanov et al., 2008).

Given the relatively small number of centenarians resident in the Agincourt DSA, I focused my age exaggeration analysis on the ratio of deaths at ages 90+ to ages 75+,  $\frac{D_{90+}}{D_{75+}}$ . As shown in Figure 6.6, Most of the substantial age exaggeration, where  $\frac{D_{90+}}{D_{75+}} > 0.15$ , is associated with the female deaths suggesting that old age reporting of females is, in general, of lower quality than that of males.

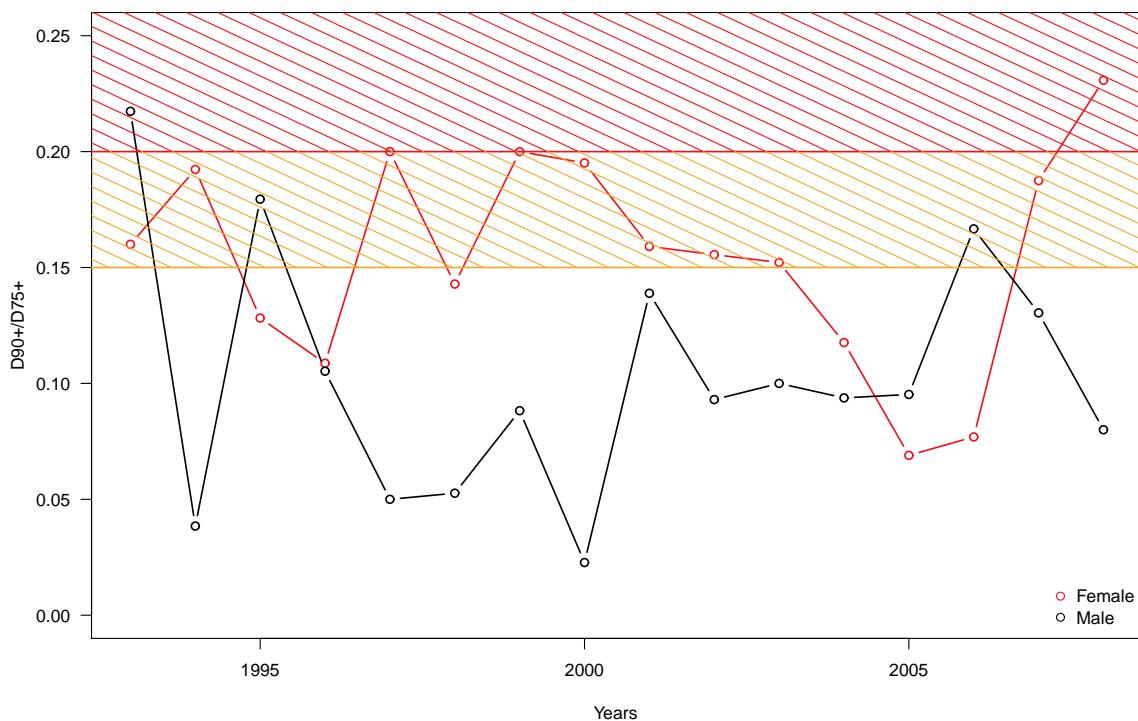


Figure 6.6: Ratio of Deaths Above 90 to Deaths above 75 for Males and Females, 1993-2008

### Plausibility of Estimated Age/Sex Patterns of Mortality

To evaluate the plausibility of estimated age/sex patterns of mortality, I examined (a) the infant fraction (defined as the ratio of the probability of death between ages 0 and 1 to the probability of death between ages 0 and 5, ie  $\frac{1q_0}{5q_0}$ ) and (b) the adult-child mortality quotient (defined as the ratio of the probability of death between ages 15 and 60 to the probability of death between ages 0 and 5, ie  $\frac{45q_{15}}{5q_0}$ ). In Figure ??, we observe that the infant fraction for females is fairly consistent over time with the infant fraction for males- suggesting that there is no systematic sex bias in the reporting of infant/child mortality. We also observe that, in general, the adult-child mortality quotient is systematically higher for males relative to that for females. This indicates that, in general, a heightened adult mortality relative to child mortality for males compared with females (or possibly a lower relative magnitude of child mortality to adult mortality for males than for females). Ngom and Clark (2003) have noted that, in South Africa during this period, male HIV-related mortality was substantially greater and older than female HIV-related mortality.



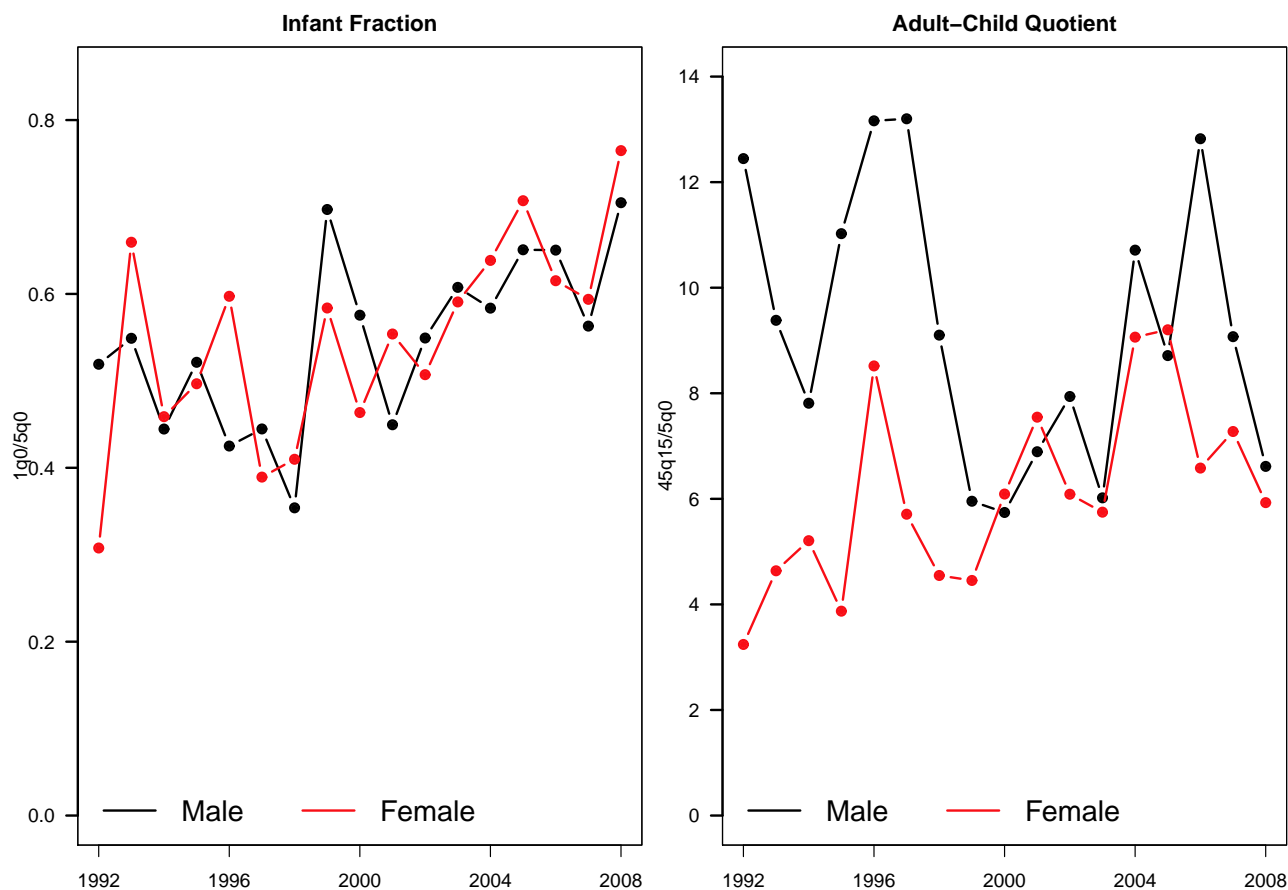


Figure 6.7: Sex-specific Probability of Death ( ${}_nq_x$ ) Ratios, Agincourt DSA, 1992-2008

## External Assessments

### Comparison of Adult Mortality Measures (e.g ${}_nq_x$ ) with HMD Data Series

We consider two issues: (i) the completeness of infant mortality (age 0 only) relative to child mortality overall (ages 0-4 inclusive), and (ii) the completeness of child mortality (ages 0-4) relative to adult mortality (ages 15-59). I examine the following mortality levels for the Agincourt DSA in comparison to typical patterns found amongst HMD countries:

1. the infant fraction, defined as the following quotient:  $\frac{1q_0}{5q_0}$ ;
2. the size of under-five mortality relative to adult mortality, described by the following quotient:  $\frac{5q_0}{45q_{15}}$ .

For these external assessments, I compared the Agincourt mortality data with all 37 mortality series in the Human Mortality Database. For ease of presentation, I showcase comparisons with the HMD series for Sweden, UK (Total), Russia, and Ukraine, as these analyses are illustrative of the overall findings from comparisons across all HMD series. When examining the relative size of infant and under-five mortality, under-five mortality observed for the Agincourt DSA were unusually high for the given level of infant mortality relative to the HMD series, as shown in Figure 6.8 and Figure 6.9. This suggests that either the level of infant mortality (relative to observed under-five mortality) in the Agincourt DSA is either unusually high compared with the historical series observed in the HMD, or that the Agincourt DSA is vulnerable to under-reporting of child mortality (ie deaths occurring between a child's first and fifth birthday). Further, there is more variability in the observed infant fractions for Agincourt DSA than for comparable observations from HMD countries.

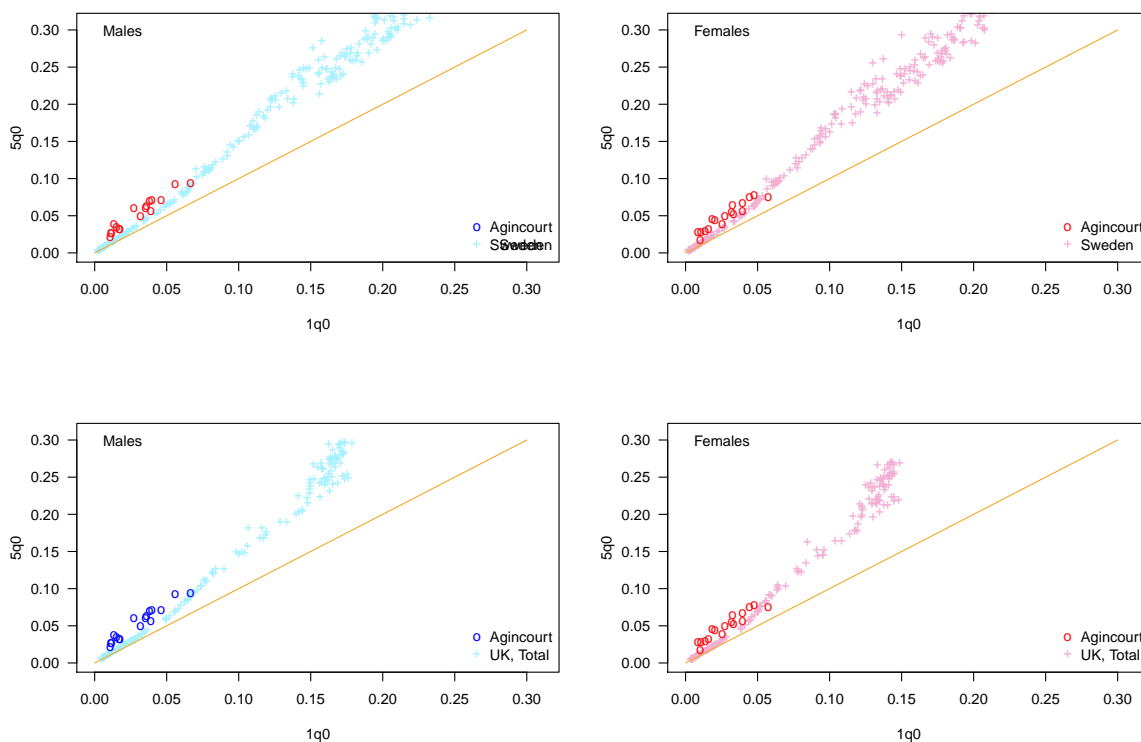


Figure 6.8: Comparison of Infant/Child Mortality Patterns by Sex with Sweden & UK, 1993-2008

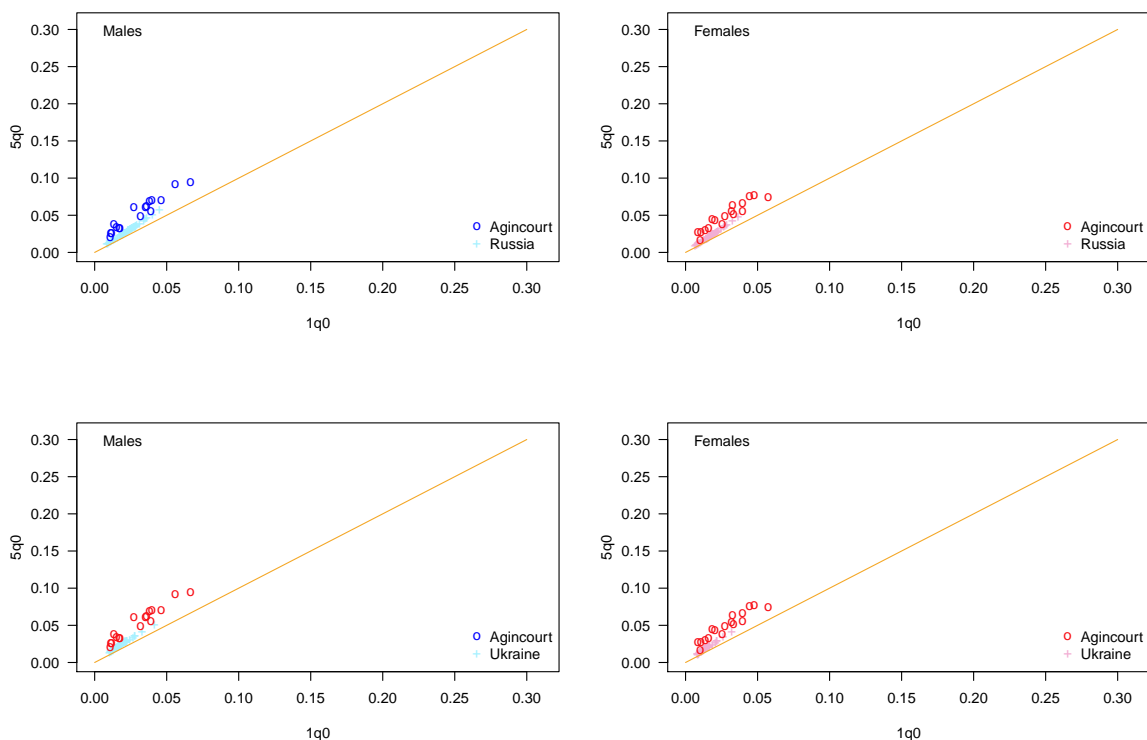


Figure 6.9: Comparison of Infant/Child Mortality Patterns by Sex with Russia & Ukraine, 1993-2008

Analysis of the infant fraction compared to  ${}_5q_0$  can be a useful means of identifying cases where the under-reporting of child mortality occurs predominantly in the first year of life. In Figure 6.10 and Figure 6.11, I also examined comparisons between  ${}_5q_0$  and the conditional probabilities of dying in the age intervals from 15 to 60 years ( ${}_{45}q_{15}$ ). These analyses are particularly useful for cases when deaths are uniformly under-reported at all ages below 5 years, as the infant fraction analyses would be a poor diagnostic in such cases. However, the under-five/adult mortality quotient is complicated in that this quotient represents both under reporting of childhood deaths and genuine situations of excess adult mortality. Further, for populations from the former Soviet Union official statistical agencies have used a non-definition of a live birth, thus complicating the cross country comparisons.

Figure 6.10 shows that the under-five/adult mortality quotient observed in Agincourt varies considerably from patterns observed in the entire UK and Sweden historical HMD series. Whereas,

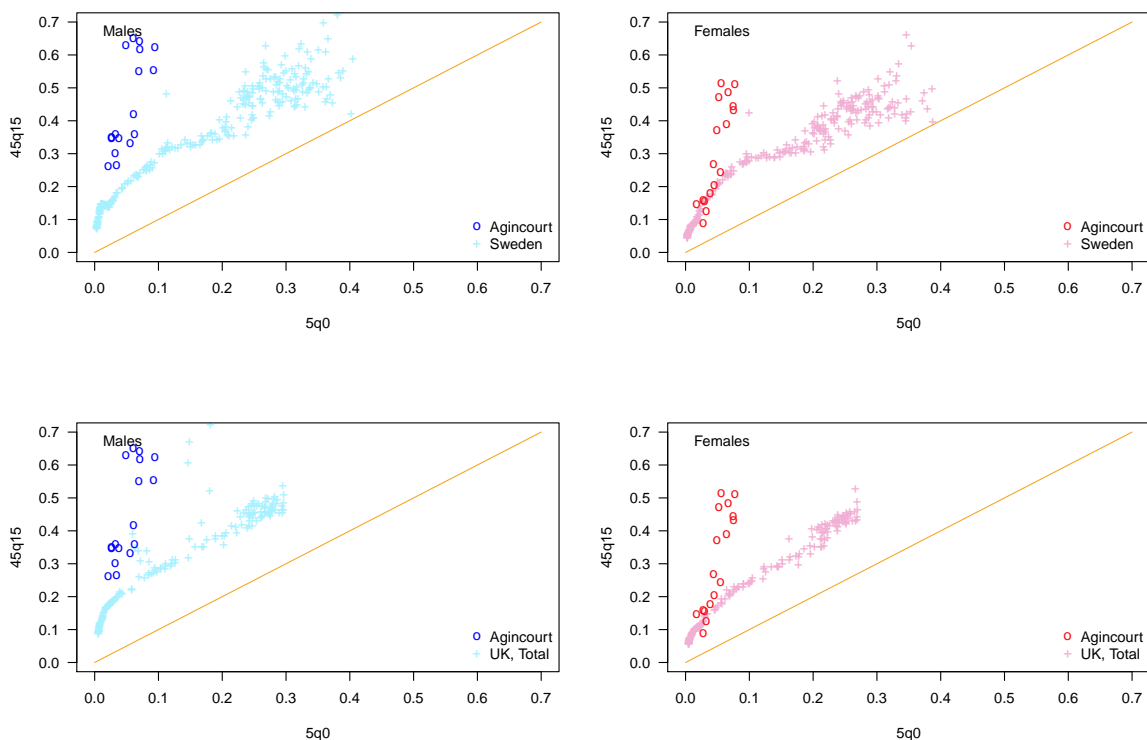


Figure 6.10: Comparison of Adult/Child Mortality Patterns by Sex with Sweden & UK, 1993-2008

comparison with HMD mortality series from Russia and Ukraine in Figure 6.11 shows that the under-five/adult patterns observed at the Agincourt DSA are reasonably close, but still more variable and extreme, to those observed in Russia and Ukraine.

The unusual under-five/adult mortality quotients observed for Russia and Ukraine are consistent with the sharp increase in cardiovascular mortality, mortality from injuries and violence, infectious and respiratory diseases following the collapse of the former Soviet Union (Denisova, 2010; Shkolnikov et al., 1998; Murphy, 2011). Whereas, the comparable patterns for under-five/adult mortality quotients observed in the Agincourt DSA have been attributed to the HIV/AIDS epidemic being primarily concentrated within the prime adult reproductive ages (Ngom and Clark, 2003).

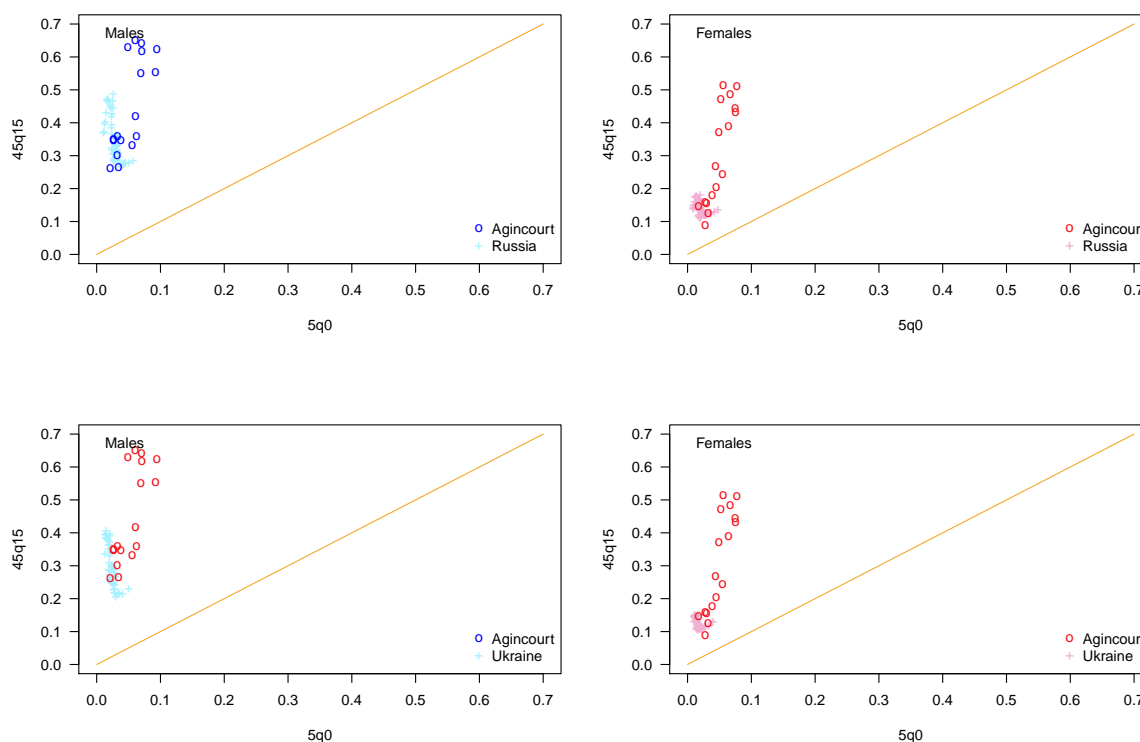


Figure 6.11: Comparison of Adult/Child Mortality Patterns by Sex with Russia & Ukraine, 1993-2008

## 6.6 Conclusions & Future Research Directions

In this chapter, I have examined the quality of mortality data from the Agincourt DSS by using some of the standard metrics used by the HMD team for both internal and external assessments of data quality. Such DSS data are an important source of demographic data in low-income countries, and are often thought to be the highest quality demographic data on contemporary populations in low-income countries. The internal assessments certainly confirm that the Agincourt DSS mortality data are less vulnerable to the sorts of reporting errors to which retrospective data (such as population censuses and household surveys) in developing countries are vulnerable, as exemplified by the internal assessments of sex ratios at birth and death, age heaping and age exaggeration of mortality data. Yet, internal assessment of the Agincourt DSS data indicate that they do have a substantially higher amount of age exaggeration and age heaping than the HMD data series. External assessments of the Agincourt DSS mortality data against HMD series indicate that (i) the Agincourt DSS data are subject to more variability than HMD mortality data, as one would expect

from a small subnational DSS, and (ii) the adult mortality patterns observed in the Agincourt DSS data, in particular, characterized by high prevalence of HIV/AIDS deviate notably from the mortality patterns observed in the HMD data series - even those of extreme mortality situations such as the observed through the 1990s in the former Societ-bloc countries.

This analysis approaches data quality from a classical demographic analysis perspective, thus providing a complementary evidentiary framework to database quality checks and field evaluations often carried out at demographic surveillance areas. However, further research is required to develop this analytical framework. In particular, this analysis could be enriched by incorporating DSS data from DSS sites neighboring the Agincourt DSS (such as other South African DSS sites like the Africa Center in KwaZulu Natal, Limpopo, and Digikale, and perhaps even the Manhicaland site in Mozambique) and also population/mortality data from South African population censuses and household surveys. Second, further development is required to develop a framework for DSS mortality data quality assessment that draws on comparisons with geographically-relevant comparisons (such as available population census data, household survey data and DSS data from surrounding areas) as well as comparisons to high quality historical data (such as those from DSS sites from further afield). Thirdly, further research is needed to explore how new approaches to coverage measurement may be applicable in the settings of DSSs, in which coverage measurement is used to develop a more effective feedback loop to enhance the continuous improvement of demographic data collection. As INDEPTH DSS data become increasingly available to researchers, with the launch of INDEPTH's iShare program, such data quality assessment will provide an important basis for analysts to distinguish data errors from actual mortality patterns.

## Chapter 7

### Conclusions

In 2015 the international community will assess progress towards MDGs. The MDGs build on Alma Alta Declaration in developing a framework for assessment of and accountability in development progress evaluation. There has been considerable effort and some commendable progress towards accelerated development progress and improved human health. Most notably, on child mortality. For example, Togo, Guinea, and Laos have all had substantial improvements in child mortality. In other countries, such as Benin and Niger there has been limited progress in reducing mortality. Whereas, in places like South Africa, Kenya, and Zimbabwe there have been mortality reversals.

Yet, many countries lack basic vital registration data that are critical for the accurate measurement of age-specific mortality rates. As a result, for some countries there is considerable uncertainty associated with mortality measurement. For example, in 2009 the United Nations Population division estimated the probability dying between ages 15 and 60 (ie  ${}_{45}q_{15}$ ) for females in Niger as 310 per 1,000, whereas the World Health Organization's estimate for the same quantity that year was 440 per 1,000.

The progress in establishing vital registration systems at the national level has been slow in recent years. Such systems are expensive to set up and maintain. Perhaps as a result, at least in part, of these considerable costs and operational challenges, population and health practitioners have focused more on the collection of household survey data, population census information, subnational demographic surveillance site data, and sample registration data. Vital registration remains the gold standard in mortality measurement, as it provides timely and reliable information on both death events and the population at risk at both national and subnational levels. As this dissertation has shown, while there are many alternative work-around solutions to mortality measurement, when comprehensive/high-quality vital registration data is not available, all of these alternative approaches come with notable limitations and trade-offs.

When examining child mortality estimation methods in low-resource settings, I found that indirect estimates are generally consistent with direct estimates, after adjustment for fertility change and birth transference, but don't add substantial additional insight beyond direct estimates. However, choice of direct or indirect method was found to be important in terms of both the adjustment for data errors and the assumptions made about fertility. Although adjusted indirect estimates are generally consistent with adjusted direct estimates, some notable inconsistencies were observed for countries that had experienced either a political or economic crisis or stalled health transition in their recent past. However, the observed inconsistencies identified suggest that the indirect method is particularly prone to bias resulting from violations of its strong assumptions about recent mortality and fertility. Hence, indirect estimates of under-five mortality rates from summary birth histories should be used only for populations that have experienced either smooth mortality declines or only short periods of excess mortality in their recent past.

When examining adult mortality estimation in low-resource settings, using historical household registration data, I found that the kin-based estimation methods, namely the orphanhood method and sibling-survival method (after adjustments are made for survivorship bias) were the more consistent with life table estimates than death distribution methods. Although unadjusted orphanhood estimates are the most consistent with life table estimates of  ${}_{45}q_{15}$ , they refer to periods about 10-15 years earlier than analogous sibling-survival and death distribution data. Though, by adjusting sibling-survival data for survivorship bias the performance of the sibling-survival method can be considerably improved.

When examining the quality of demographic surveillance data from the Agincourt DSS site using data quality assessment methods used for the Human Mortality Database, I found that such demographic surveillance data are less vulnerable to the sorts of reporting errors to which retrospective data (such as population censuses and household surveys) in developing countries are vulnerable. Although internal and external assessments of the Agincourt DSS data indicated that such data are characterized by more substantial age heaping and age exaggeration errors than in most HMD data series. Further, mortality series constructed from such DSS data display substantially more variability than HMD mortality series, given that they represent only small subnational populations. Nevertheless, such demographic surveillance data like those from the INDEPTH Network do provide a strong empirical basis for the assessment of health and mortality transitions in low-income countries.

These findings all show that indirect methods can be useful in certain stylized situations. But in situations characterized by stalled health transitions and economic and political crises, arguably the situations where we need reliable mortality measurement the most, such indirect methods are often subject to considerable biases and limitations. These findings build on previous work that has examined the limitations of using incomplete death registration data and mortality data from the Demographic and Health Surveys to estimate child and adult mortality (Gakidou et al., 2004;



Murray et al., 2010). In doing so, they call into question the continued reliance on work-around census and survey based methods as a long-term approach to improving mortality measurement and therefore supporting the effective reduction in premature deaths and burden of preventable diseases. The findings in this dissertation also clarify the circumstances in which indirect methods can be used effectively and reliably when comprehensive civil registration systems are not available - a situation that will likely continue for some time, even if there is an imminent, renewed political will and scaling up of civil registration systems in developing countries.

## Bibliography

- AbouZahr, Carla; Gollogly, Laragh, and Stevens, Gretchen. Better Data Needed: Everyone Agrees, But No One Wants to Pay. *Lancet*, 375:619–621, 2010.
- Adetunji, Jacob. Infant Mortality Levels in Africa: Does Method of Estimation Matter? *Genus*, 52:89–106, 1996.
- Alfani, Guido. Population and Environment in Northern Italy During the 16th Century. In *Proceedings of the European Population Conference*, Liverpool, UK, 2006.
- Arnold, David. *Famine: Social Crisis and Historical Change*. Basil Blackwell, Oxford, 1988.
- Aryal, Umesh; Vaidya, Abhinav; Shakya-Vaidya, Suraj; Petzold, Max, and Krettek, Alexandra. Establishing a Health Demographic Surveillance Site in Bhaktapur District, Nepal: Initial Experiences and Findings. *BMC Research Notes*, 5(1):489, 2012.
- Atlman, Lawrence K. The Doctor's World: Rising from the Ranks to Lead the World Health Organization. *New York Times*, 22 July, 2003.
- Aziz, K.M.A. and Mosley, Henry W. The History, Methodology and Main Findings of the Matlab Project in Bangladesh. In Das Gupta, Monica; Aaby, Peter; Garenne, Michel, and Pison, Giles, editors, *Prospective Community Studies in Developing Countries*,, pages 28–53. Clarendon Press, Oxford, 1997.
- Baiden, Frank; Hodgson, Abraham, and Binka, Fred N. Demographic Surveillance Sites and Emerging Challenges in International Health. *Bulletin of the World Health Organization*, 84(3): 183–186, 2006.
- Bangha, Martin; Diagne, Alioune; Bawah, Ayaga, and Sankoh, Osman. Monitoring the Millennium Development Goals: the Potential Role of the INDEPTH Network. *Global Health Action*, 3:10.3402, 2010.
- Becker, Stan and Mahmud, Simeen. A Validation Study of Backward and Forward Pregnancy Histories in Matlab, Bangladesh. WFS Scientific Report 52, WFS, Voorburg, 1984.

- Begg, Stephen; Rao, Chalapati, and Lopez, Alan D. Design Options for Sample-based Mortality Surveillance. *International Journal of Epidemiology*, 34(5):1080–1087, 2005.
- Bell, Robert M. and Cohen, Michael L. *Coverage Measurement in the 2010 Census*. National Research Council, 2008.
- Bennett, Neil G. and Horiuchi, Shiro. Estimating the Completeness of Death Registration in a Closed Population. *Population Index*, 47:207–221, 1981.
- Bennett, Neil G. and Horiuchi, Shiro. Mortality Estimation from Registered Deaths in Less Developed Countries. *Demography*, 21(2):217–233, 1984.
- Benzler, Justus; Herbst, Kobus, and MacLeod., Bruce. A Data Model for Demographic Surveillance. Unpublished Manuscript, 1998.
- Berhane, Yemane; Wall, Stig; Kebede, Derege; Emmelin, Anders; Enquesselassie, Fikre; Byass, Peter; Muhe, Lulu; Andersson, Tobias; Deyessa, Negussie; Hogberg, Ulf; Gossaye, Yegomawork; Alem, Atalay, and Dahlblom, Kjerstin. Establishing an Epidemiological Field Laboratory in Rural Areas - Potentials for Public Health Research and Interventions. The Butajira Rural Health Programme 1987-1999. *Ethiopian Journal of Health and Development*, 13(S1):1–47, 1999.
- Bhat, P. Mari N. Completeness of India's Sample Registration System: An Assessment Using the General Growth Balance Method. *Population Studies*, 56(2):119–34, 2002.
- Bhat, P.N. Mari. Age Misreporting and its Impact on Adult Mortality Estimates in South Asia. *Demography*, 24(1):1, 1995.
- Bielenstein, Hans. *The Bureaucracy of Han Times*. Cambridge University Press, Cambridge, 1980.
- Blacker, John G. C.; Fernandez, Raul, and Timaeus, Ian M. *WFS Scientific Reports*, chapter The Estimation of Adult Mortality from the Mortality Module of the WFS Household Schedule, page . International Statistical Institute, 1986.
- Blacker, John G.C. The Estimation of Adult Mortality in Africa from Data on Orphanhood. *Population Studies*, 31:107–128, 1977.
- Blacker, John G.C. The Impact of AIDS on Adult Mortality: Evidence From National and Regional Statistics. *AIDS*, Suppl 2:519–526, June 2004.
- Bobadilla, Jose Luis; Costello, Christine A., and Mitchell, Faith. *Premature Death in the New Independent States*. The National Academies Press, 1997. Committee on Population, National Research Council.
- Boerma, J. Ties and Stansfield, Sally K. Health Statistics Now: Are We Making the Right Investments? *The Lancet*, 369(9563):779 – 786, 2007.

- Bongaarts, John. The Causes of Stalling Fertility Transitions. *Studies in Family Planning*, 37(1): 1–16, 2006.
- Bongaarts, John. Fertility Transitions in Developing Countries: Progress or Stagnation? *Studies in Family Planning*, 39(2):105–110, 2008.
- Bourgeois-Pichat, Jean. De La Mesure de La Mortalité Infantile. *Population*, 1(1):53–68, 1946.
- Brass, William. Use of Census or Survey Data for the Estimation of Vital Rates. E/CN.14/CAS.4/57. African Seminar on Vital Statistics., 1964a.
- Brass, William. Use of Census or Survey Data for the Estimation of Vital Rates. E/CN.14/CAS.4/57. African Seminar on Vital Statistics., 1964b.
- Brass, William. Methods of Analysis and Estimation. In Brass, William; Coale, Ainsley; Demeny, Paul, and Heisel, D., editors, *The Demography of Tropical Africa*. Princeton University Press, London, 1968.
- Brass, William. Methods for Estimating Fertility and Mortality From Limited and Defective Data. Technical report, Chapel Hill: The University of North Carolina at Chapel Hill, International Program for Laboratories for Population Statistics., 1971a.
- Brass, William. Methods for Estimating Fertility and Mortality from Limited and Defective Data. Technical report, Chapel Hill: The University of North Carolina at Chapel Hill, International Program for Laboratories for Population Statistics., 1971b.
- Brass, William. Methods for Estimating Fertility and Mortality from Limited and Defective Data. Technical report, Chapel Hill: The University of North Carolina at Chapel Hill, International Program for Laboratories for Population Statistics., 1975.
- Brass, William and Bamgboye, Elijah. The Time Location of Reports of Survivorship: Estimates for Maternal and Paternal Orphanhood and the Ever-Widowed. Technical report, Centre for Population Studies, London School of Hygiene and Tropical Medicine, London, 1981.
- Brass, William; Coale, Ainsley; Demeny, Paul, and Heisel, D. *The Demography of Tropical Africa*. Princeton University Press, 1968.
- Breckenridge, Keith. The Biometric State: the Promise and Peril of Digital Government in the New South Africa. *Journal of African Studies*, 31(2):267–282, 2005.
- Campbell, Cameron and Lee, James. A Death in the Family: Household Structure and Mortality in Rural Liaoning, Life-Event and Time-Series Analysis, 1792-1867. *The History of the Family: An International Quarterly*, 1(3):297–328, 1996.

- Campbell, Cameron and Lee, James. Price Fluctuations, Family Structure and Mortality in Two Rural Chinese Populations: Household Responses to Economic Stress in Eighteenth- and Nineteenth-Century Liaoning. In Bengtsson, T. and Saito, O., editors, *Population and the Economy: From Hunger to Modern Economic Growth*, pages 371–420. Oxford University Press, Oxford, 2000.
- Campbell, Cameron and Lee, James. When Husbands and Parents Die: Widowhood and Orphanhood in Late Imperial Liaoning, 1789-1909. In Derosas, R. and Oris, M., editors, *When dad died*, pages 313–334. Peter Lang, Bern, 2002.
- Campbell, Cameron and Lee, James. Disability, Disease, and Mortality in Northeast China. California Center for Population Research Working Paper Series, 2003.
- Campbell, Cameron and Lee, James. Mortality and Household in Seven Liaoning Populations, 1749-1909. In Bengtsson, T.; Campbell, C., and Lee, J., editors, *Life Under Pressure: Mortality and Living Standards in Europe and Asia, 1700-1900*, pages 293–324. MIT Press, Cambridge, MA, 2004.
- Campbell, Cameron and Lee, James. Long-term Mortality Consequences of Childhood Family Context in Liaoning, China, 1749-1909. *Social Science and Medicine*, 68:1641–1648, 2009.
- Caselli, Grazielli; Mesle, France, and Vallin, Jacques. Epidemiologic Transition Theory Exceptions. *Genus*, 58(1):pp. 9–51, 2002. ISSN 00166987.
- Chandramohan, Daniel; Shibuya, Kenji; Setel, Philip; Cairncross, Sandy; Lopez, Alan D; Murray, Christopher J.L; Zaba, Basia; Snow, Robert W., and Binka, Fred. Should Data From Demographic Surveillance Systems Be Made More Widely Available to Researchers? *PLoS Medicine*, 5(2):e57, 02 2008.
- Chen, C.C. and Bunge, F.M. *Medicine in Rural China: a Personal Account*. University of California Press, Berkeley, 1989.
- Chiang, Chin Long. *The Life Table and its Applications*. Robert E. Krieger Publishing Company, Malabar, Florida, 1984.
- Clark, Samuel. Evaluating Demographic Surveillance: Adult Mortality. Presentation at Conference on ‘Adult Mortality in the Developing World: Methods and Measures’ sponsored by the Hopkins Population Center, Johns Hopkins University and the Center for Economics and Demography of Aging, University of California, Berkeley. Marconi Conference Center, Marin County, California, 2004.
- Clark, Samuel J. A General Temporal Data Model and the Structured Population Event History Register. *Demographic Research*, 15(7):181–252, 2006.

- Coale, Ainsley and Demeny, Paul. *Regional Model Life Tables and Stable Populations*. Princeton University Press, Princeton, 1966.
- Collinson, MA; Tollman, SM, and Kahn, K. Migration, Settlement Change and Health in Post-apartheid South Africa: Triangulating Health and Demographic Surveillance with National Census Data. *Scandinavian Journal Public Health*, 35(Suppl 69):77–84, 2007.
- Denisova, Irina. Adult mortality in russia. *The Economics of Transition*, 18(2):333–363, 04 2010.
- Diallo, D.A.; Habluetzel, A.; Cousens, S.N., and Esposito, F. Comparison of Two Methods of Assessing Child Mortality in Areas Without Comprehensive Registration Systems. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, 90:610–613, 1996.
- Dorrington, Rob; Bourne, D; Bradshaw, Debbie; Laubscher, R, and Timaeus, Ian M. The Impact of HIV/AIDS on Adult Mortality in South Africa. South African Medical Research Council, Tygerberg, 2001.
- Elo, Irma and Preston, Samuel. Estimating African-American Mortality from Inaccurate Data. *Demography*, 31:427–458, 1994.
- Ewbank, Douglas. *Age Misreporting and Age-Selective Underenumeration: Sources, Patterns and Consequences for Demographic Analysis*. National Academy Press, 1981.
- Eyler, John M. *Victorian Social Medicine: The Ideas and Methods of William Farr*. Johns Hopkins University Press, Baltimore, 1979.
- Farr, William. Vital Statistics. In J.R., McCulloch, editor, *A Statistical Account of the British Empire: Exhibiting its Extent, Physical Capacities, Population, Industry, and Civil and Religious Institutions*, pages 567 – 601. C. Knight, 1837.
- Farris, W.W. *Population, Disease, and Land in Early Japan, 645-900*. Harvard-Yenching Institute Monograph Series. Council on East Asian Studies, Harvard University, and the Harvard Yenching Institute, and distributed by the Harvard University Press, 1995.
- Feeney, Griffith. Estimating Infant Mortality Trends from Child Survivorship Data. *Population Studies*, 34(1):109–128, 1980.
- Feeney, Griffith. The Impact of HIV/AIDS on Adult Mortality in Zimbabwe. *Population and Development Review*, 27(4):pp. 771–780, 2001. ISSN 00987921.
- Fotterell, Edward; Byass, Peter, and Berhane, Yemane. Demonstrating the Robustness of Population Surveillance Data: Implications of Error Rates on Demographic and Mortality Estimates. *BMC Medical Research Methodology*, 8(1):13, 2008.

- Freedman, D.A. and Wachter, K.W. Heterogeneity and Census Adjustment for the Inter-censal Base. *Statistical Science*, 9:476–485, 1994.
- Gakidou, Emmanuela; Hogan, Margaret, and Lopez, Alan D. Adult Mortality: Time for a Reappraisal. *International Journal of Epidemiology*, 33(4):710–717, 2004.
- Gakidou, Emmanuela E. and King, Gary. Death by Survey: Estimating Adult Mortality Without Selection Bias From Sibling Survival Data. *Demography*, 43:569–585, 2006. doi: 10.1353/dem.2006.0024.
- Garenne, Michel. The Political Economy of an Urban Famine Antananarivo, 1985â6. *IDS Bulletin*, 33(4):55–62, 2002.
- Garenne, Michel. Fertility Changes in Sub-Saharan Africa. DHS Comparative Reports No. 18., 2008.
- Garenne, Michel and Friedberg, F. Accuracy of Indirect Estimates of Maternal Mortality. *Studies in Family Planning*, 28:132–142, 1997.
- Garenne, Michel and Gakusi, Eneas. Health Transitions in Sub-Saharan Africa: Overview of Mortality Trends in Children Under 5 Years Old (1950-2000). *Bulletin of the World Health Organization*, 84:470–478, 2006.
- Garenne, Michel; Das Gupta, Monica; Pison, Giles, and Aaby, Peter. Introduction. In Das Gupta, Monica; Aaby, Peter; Garenne, Michel, and Pison, Giles, editors, *Prospective Community Studies in Developing Countries*, pages 1–18. Clarendon Press, Oxford, 1997.
- Gautier, Etienne and Henry, Louis. *La Population de Crulai, Paroisse Normande*. Presses Universitaires de France, Paris, 1958.
- Goubert, Pierre. *Beauvais et les Beauvaisois de 1600 a 1730*, volume 1. SEVPEN, Paris, 1960.
- Grassly, Nicholas C.; Lewis, James J. C.; Mahy, Mary; Walker, Neff, and Timaeus, Ian M. Comparison of Household-Survey Estimates with Projections of Mortality and Orphan Numbers in Sub-Saharan Africa in the Era of HIV/AIDS. *Population Studies*, 58(2):pp. 207–217, 2004. ISSN 00324728.
- Graunt, John. *Natural and Political Observation Mentioned in a Following Index, and Made Upon the Bills of Mortality*. John Martyn, Printer to the Royal Society, London, 1662.
- Hald, Anders. *John Graunt and the Observations Made Upon the Bills of Mortality, 1662*, pages 81–105. John Wiley & Sons, Inc., 2005.

- Helleringer, Stéphane; Duthé, Géraldine; Kanté, Almamy Malick; Andro, Armelle; Sokhna, Cheikh; Trape, Jean-Francois, and Pison, Gilles. Misclassification of Pregnancy-related Deaths in Adult Mortality Surveys: Case Study in Senegal. *Tropical Medicine & International Health*, 18(1):27–34, 2013a.
- Helleringer, Stephane; Duthé, Geraldine, and Pison, Giles. Reporting Errors in Survey Data on Adult Mortality: Results From a Record Linkage Study in Senegal. *Demography*, 50: (Forthcoming), 2013b.
- Henry, Louis. Mesure Indirecte de la Mortalite des Adultes. *Population*, 15:457–466, 1960.
- Heuveline, Patrick and Clark, Sam. Model Schedules of Mortality. In Rogers, Richard G. and Crimmins, Eileen M., editors, *International Handbook of Adult Mortality*, chapter 25, pages 511–532. Springer, 2011.
- Hill, K. and Thomas, K.J.A. Evaluating the Performance of Death Distribution Methods for Estimating Death Registration Completeness: Applications to Data from High Income Countries. In *Proceedings of the Annual Meeting of the Population Association of America*, 2007.
- Hill, K. and Trussell, J. Further Developments in Indirect Mortality Estimation. *Population Studies*, 31(2):313–334, 1977.
- Hill, Ken. Making Deaths Count. *Bulletin of the World Health Organization*, 84:162, 2006.
- Hill, Ken; Pande, Rohini; Mahy, Mary, and Jones, Gareth. Trends in Child Mortality. Technical report, UNICEF, New York, 1999.
- Hill, Kenneth. Estimating Census and Death Registration Completeness. *Asian Pacific Population Forum*, 1:8–13, 1987.
- Hill, Kenneth. Methods for Measuring Adult Mortality in Developing Countries: a Comparative Review. Research Paper . No. 01.13, Harvard Burden of Disease Unit, 2000.
- Hill, Kenneth. Adult Mortality in the Developing World: What We Know and How We Know It. UN/POP/MORT/2003/1, 2003. Department of Economic and Social Affairs, Population Division, United Nations.
- Hill, Kenneth and Brass, William. Estimating Adult Mortality from Orphanhood. *International Population Conference, Liege*, 3:111–123, 1973.
- Hill, Kenneth and Choi, Yoonjung. Death Distribution Methods for Estimating Adult Mortality: Sensitivity Analysis with Simulated Data Errors. In *Proceedings of the Adult Mortality in Developing Countries Workshop, 11 July 2004. The Marconi Center, Marin County, California.*, 2004.



- Hill, Kenneth and Figueroa, Maria-Elena. Child Mortality Estimation by Time Since First Birth. In Zaba, Basia and Blacker, John, editors, *Brass Tacks: Essays in Medical Demography*, pages 9–19. Athlone, London, 2001.
- Hill, Kenneth; Choi, Yoonjoung, and Timaeus, Ian. Unconventional Approaches to Mortality Estimation. *Demographic Research*, 13(12):281–300, 2005. doi: 10.4054/DemRes.2005.13.12.
- Hogan, Margaret C; Foreman, Kyle J; Naghavi, Mohsen; Ahn, Stephanie Y; Wang, Mengru; Makela, Susanna M; Lopez, Alan D; Lozano, Rafael, and Murray, Christopher JL. Maternal Mortality for 181 countries, 1980-2008: a Systematic Analysis of Progress Towards Millennium Development Goal 5. *The Lancet*, 375(9726):1609–1623, 2010. ISSN 0140-6736. doi: 10.1016/S0140-6736(10)60518-1.
- Human Mortality Database, . Publications Using the HMD or BMD. Last accessed on April 2, 2013., 2008.
- INDEPTH Network, . Founding Document for An International Network of Field Sites With Continuous Demographic Evaluation of Populations and Their Health in Developing Countries, 1998.
- INDEPTH Network, . Assessing the Quality of DSS Data. In *Population, Health, and Survival at INDEPTH Sites*, volume 1 of *Population and health in developing countries / International Development Research Center*, chapter 5, pages 43–50. International Development Research Center, Ottawa, Canada, 2002.
- International Conference on Primary Health Care, . Declaration of Alma-Ata. *The Lancet*, 312(8098):1040 – 1041, 1978. ISSN 0140-6736. doi: 10.1016/S0140-6736(78)92354-1. ;ce:title;Originally published as Volume 2, Issue 8098; ;ce:title;.
- Jahn, Andreas; Branson, Keith; Crampin, Amelia C.; Fine, Paul EM; Glynn, Judith R.; McGrath, Nuala; Mwafilaso, Johnbosco; Mwaiyeghele, Elenaus; Mwinuka, Venance, and Zaba, Basia. Evaluation of a Village-informant Driven Demographic Surveillance System in Karonga, Northern Malawi. *Demographic Research*, 16(8):219–248, 2007.
- Jdanov, D.A.; Jasilionis, D.; Soroko, E.L.; Rau, R., and Vaupel, J.W. Beyond the Kannisto-Thatcher Database on Old Age Mortality: An Assessment of Data Quality at Advanced Ages. Unpublished Manuscript, 2008.
- Kahn, Kathleen; Tollman, Stephen M.; Collinson, Mark A.; Clark, Samuel J.; Twine, Rhian; Clark, Benjamin D.; Shabangu, Mildred; Gomez-Olive, ; Xavier, Francesc; Mokoena, Obed, and Garenne, Michel. Research into Health, Population and Social Transitions in Rural South Africa: Data and Methods of the Agincourt Health and Demographic Surveillance System. *Scandinavian Journal of Public Health*, 35(3):8 – 20, 2007.

- Lavallée, Pierre. *Indirect Sampling*. Springer series in statistics. Springer, New York, 1 edition edition, 2007. ISBN 0387707786.
- Lee, James and Campbell, Cameron. China Multi-Generational Panel Dataset, Liaoning (CMGPD-LN), 1749-1909. User Guide. Technical report, Inter-university Consortium for Political and Social Research, Ann Arbor, MI, 2011a. Version 1.4.
- Lee, James Z. and Campbell, Cameron D. China Multi-Generational Panel Dataset, Liaoning (CMGPD-LN), 1749-1909. Inter-university Consortium for Political and Social Research (ICPSR), 2011b.
- Luy, Marc. Estimating Mortality Differences in Developed Countries From Survey Information on Maternal and Paternal Orphanhood. *Demography*, 49:607–627, 2012.
- Luy, Marc; Di Giulio, Paola, and Caselli, Graziella. Differences in Life Expectancy by Education and Occupation in Italy, 1980-94: Indirect Estimates from Maternal and Paternal Orphanhood. *Population Studies*, 65(2):137–155, 2011.
- Machiyama, Kazuyo. A Re-examination of Recent Fertility Declines in Sub-Saharan Africa. DHS Working Papers No. 68, 2010.
- Madhavan, Sangeetha; Collinson, Mark; Townsend, Nicholas W.; Kahn, Kathleen, and Tollman, Stephen. The Implications of Long-term Community Involvement for the Production and Circulation of Population Knowledge. *Demographic Research*, 17(13):369–388, 2007.
- Mahapatra, Prashant and Rao, Chalapati. Cause of Death Reporting Systems in India: a Performance Analysis. *National Medical Journal of India*, 14:154–162, 2001.
- Mahapatra, Prashant; Shibuya, Kenji; Lopez, Allan D.; Coullare, F.; Notzon, F.Z.; Rao, C., and Szreter, Simon. Civil Registration Systems and Vital Statistics: Successes and Missed Opportunities. *Lancet*, 370(9599):1653–1663, 2007a.
- Mahapatra, Prashant; Shibuya, Kenji; Lopez, Allan D.; Coullare, Françoise; Notzon, F.Z.; Rao, Chalapati, and Szreter, Simon. Civil Registration Systems and Vital Statistics: Successes and Missed Opportunities. *Lancet*, 370(9599):1653–1663, 2007b.
- Masquelier, Bruno. Adult Mortality From Sibling-Survival Data: A Reappraisal of Selection Bias. *Demography*, 50(1):207–28, 2013.
- Mathers, Colin D.; Fat, Doris Ma; Inoue, Mie; Rao, Chalapati, and Lopez, Alan D. Counting the Dead and What They Died From: An Assessment of the Global Status of Cause of Death Data. *Bulletin of the World Health Organization*, 83:171–177, 2005.
- MDG Africa Steering Group, . Achieving the Millennium Development Goals in Africa, 2008.

- Murphy, Michael J. Adult mortality in the former soviet union. In *International handbook of adult mortality. International handbooks of population*, volume 2, pages 83–100. Springer, February 2011. © 2011 Springer Science+Business Media V.B.
- Murray, Chris; Laakso, Thomas; Shibuya, Kenji; Hill, Ken, and Lopez, Alan. Can We Achieve Millennium Development Goal 4? New Analysis of Country Trends and Forecasts of Under-5 Mortality to 2015. *The Lancet*, 370:1040–1054, 2007.
- Murray, Chris J. L.; Ferguson, Brodie D.; Lopez, Allan D.; Guillot, Michel; Salomon, Josh A., and Ahmad, O. Modified Logit Life Table System: Principles, Empirical Validation, and Application. *Population Studies*, 57(2):165–182, July 2003. ISSN 0032-4728.
- Murray, Christopher J.L.; Rajaratnam, Julie K.; Marcus, Jacob; Laakso, Thomas, and Lopez, Allan D. What Can We Conclude from Death Registration: Improved Methods for Evaluating Completeness. *PLoS Medicine*, 7(4):e1000262, 2010.
- Nadhamuni, Srikanth. Aadhaar: The Implementation of the Largest National ID Project in the World, 2012. Invited Lecture on September 13, 2012 at the Center for South Asia Studies, University of California, Berkeley.
- Ngom, Pierre and Clark, Samuel. Adult mortality in the era of HIV/AIDS: sub-saharan africa, 2003. UN/POP/MORT/2003/3.
- Olshansky, S.J. and Ault, A.B. The Fourth Stage of the Epidemiologic Transition: The Age of Delayed Degenerative Diseases. *Milbank Quarterly*, 64(3):355–391, 1986.
- Olshansky, S.J.; Carnes, B.A.; Rogers, R.G., and Smith, L. Emerging Infectious Diseases: The Fifth Stage of the Epidemiological Transition. *World Health Statistics Quarterly*, 51(2):207–17, 1998.
- Omran, Abdel R. The Epidemiological Transition: A Theory of the Epidemiology of Population Change. *The Milbank Quarterly*, 49(4):509–538, 1971.
- Page, H. J. and Wunsch, G. Parental Survival Data: Some Results of the Application of Ledermann's Model Life Tables. *Population Studies*, 30(1):59–76, 1976. PMID: 22091853.
- Palloni, Alberto and Heligman, Larry. Re-estimation of Structural Parameters to Obtain Estimates of Mortality in Developing Countries. *Population Bulletin of the United Nations*, 18:10–33, 1985.
- Pedersen, Jon. Child Mortality Estimation: Optimizing Choice of Time Periods for Direct Estimates. *PLoS Medicine*, 9(8):e1001296, 2012.

- Pison, Giles and Langaney, A. The Level and Age Pattern of Mortality in Bandafassi (Eastern Senegal): Results From a Small-Scale and Intensive Multi-Round Survey. *Population Studies*, 39(3):387–405, 1985.
- Pison, Giles and Langaney, Andre. Age Patterns of Mortality in Eastern Senegal: Comparison of Micro and Survey Approaches. In Caldwell, J.C.; Hill, A.G., and Hill, V., editors, *Micro-Approaches to Demographic Research*, pages 297–317. Kegan Paul International, London, 1988.
- Pison, Gilles. Population Observatories as Sources of Information on Mortality in Developing Countries. *Demographic Research*, S4(13):301–334, 2005.
- Prazak, Miroslava and Booth, Heather. Measurement and Meaning : Community-Based Research on Child Mortality in Rural Kenya. Working Papers in Demography, No. 59, Research School of Social Sciences, Australian National University, 1995.
- Preston, Samuel; Elo, Irma; Rosenwaive, I., and Hill, M. African-American Mortality at Older Ages: Results of a Matching Study. *Demography*, 33(2):193–209, 1996.
- Preston, Samuel; Elo, Irma, and Stewart, Quincy. Effects of Age Misreporting on Mortality Estimates at Older Ages. *Population Studies*, 53:2, 1999.
- Preston, Samuel H. The Changing Relation Between Mortality and Level of Economic Development. *Population Studies*, 29(2):231, 1975.
- Preston, Samuel H. *Mortality Patterns in National Populations: With Special Reference to Recorded Causes of Death*. Academic Press, New York, 1976.
- Preston, Samuel H. The Changing Relation Between Mortality and Level of Economic Development. *International Journal of Epidemiology*, 36(3):484–490, 2007.
- Preston, Samuel M. Mortality in Childhood: Lessons from WFS. In Cleland, John and Hobcraft, John, editors, *Reproductive change in developing countries: Insights from the World Fertility Survey*, pages 253–272. Oxford University Press, 1985.
- Prewitt, Kenneth. Accuracy and Coverage Evaluation: Statement on the Feasibility of Using Statistical Methods to Improve the Accuracy of Census 2000. *Federal Register*, 65:38373–38398, 2000.
- Pullum, Thomas. An Assessment of Age and Date Reporting in The DHS Surveys, 1985-2003. DHS methodological reports, no. 5, Macro International, 2006.
- Pullum, Thomas and Sullivan, Jeremiah. An assessment of the credibility of child mortality declines estimated from DHS mortality rates. In *Paper presented at the Annual Meeting of the Population Association of America, New Orleans, LA., 2008*.

- Pullum, T.W. and Stokes, S. Lynne. Identifying and Adjusting for Recall Error, With Application to Fertility Surveys. In Lyberg, Lars and Paul Biemer, et al., editors, *Survey Measurement and Process Quality*, pages 711–732. John Wiley and Sons, New York, 1997.
- Rajaratnam, JK; Marcus, JR; Flaxman, AD; Wang, H; Levin-Rector, A; Dwyer, L; Costa, M; AD, AD Lopez, and CJL, CJL Murray. Neonatal, Postneonatal, Childhood, and Under-5 Mortality For 187 Countries, 1970-2010: A Systematic Analysis of Progress Towards Millennium Development Goal 4. *Lancet*, 375:1988–2008, May 2010a.
- Rajaratnam, JK; Tran, LN; Lopez, AD, and Murray, CJL. Measuring Under-Five Mortality Validation of New Low-Cost Methods. *PLoS Medicine*, 7(4):e1000260, 2010b.
- Rajaratnam, Julie K.; Tran, Linda N.; Lopez, Allan D., and Murray, Chris J.L. Measuring Under-Five Mortality Validation of New Low-Cost Methods. *PLoS Medicine*, 7(4):e1000260, 2010c.
- Rao, Chalapati. Breathing Life into Mortality Data Collection. *Science*, 333:1702, 2011.
- Rao, Chalapati; Lopez, Alan D.; Yang, Gonghuan; Begg, Stephen, and Ma, Jiemin. Evaluating National Cause-of-death Statistics: Principles and Application to the Case of China. *Bulletin of the World Health Organization*, 83:618 – 625, 08 2005.
- Registrar General of India, . Estimated Birth Rate, Death Rate, Natural Growth Rate and Infant Mortality Rate, 2004, 2006. SRS Bulletin 40.
- Reidpath, DD and Allotey, P. Infant Mortality Rate as an Indicator of Population Health. *Journal of Epidemiology and Community Health*, 57(5):344–346, 2003.
- Reniers, Georges; Masquelier, Bruno, and Gerland, Patrick. Adult Mortality in Africa. In Rogers, Richard G. and Crimmins, Eileen M., editors, *International Handbook of Adult Mortality*, volume 2 of *International Handbooks of Population*, pages 151–170. Springer Netherlands, 2011. ISBN 978-90-481-9995-2. doi: 10.1007/978-90-481-9996-9\_7.
- Robertson, L.; Gregson, Simon; Madanhire, C.; Walker, C.; Mushati, N.; Garnett, P., and Nyamukapa, C. Discrepancies Between UN Models and DHS Survey Estimates of Maternal Orphan Prevalence: Insights From Analyses of Survey Data From Zimbabwe. *Sexually Transmitted Infections*, 84(S1):57–62, 2008.
- Rutenberg, Naomi; Boerma, Ties; Sullivan, Jerry, and Croft, Trevor. Direct and Indirect Estimates of Maternal Mortality with Data on the Survivorship of Sisters: Results from the Bolivia DHS”. In *Presented at the Annual Meeting of the Population Association of America*, 1990.
- Rutstein, Shea O. and Rojas, George. Guide to DHS Statistics. Technical report, Macro ORC, Calverton, MD, 2006.

- Sanga, Dimitri. The Challenges of Monitoring and Reporting on the Millennium Development Goals in Africa by 2015 and beyond. *The African Statistical Journal*, 12:104–118, 2011.
- Sankoh, Osman and Byass, Peter. The INDEPTH Network: Filling Vital Gaps in Global Epidemiology. *International Journal of Epidemiology*, 41(3):579–588, 2012.
- Sankoh, Osman; Herbst, Abraham J; Juvekar, Sanjay; Tollman, Stephen; Byass, Peter, and Tanner, Marcel. INDEPTH Launches a Data Repository and INDEPTHStats. *The Lancet Global Health*, 1(1), July 2013.
- Schoumaker, Bruno. Stalls and Reversals in Fertility Transitions in Sub-Saharan Africa: Real or Spurious? Document de travail SPED, 2009.
- Sekar, Chandra C. and Deming, Edwards W. On a Method of Estimating Birth and Death Rates and the Extent of Registration. *Journal of the American Statistical Association*, 44(245):101–115, 1949.
- Sen, Amartya. Famines as Failures of Exchange Entitlements. *Economic and Political Weekly*, 11 (31):1273–1280, 1976.
- Sen, Amartya. Equality of What? *The Tanner Lecture on Human Values*, I:197–220, 1980.
- Sen, Amartya. *Poverty and Famines: an Essay on Entitlement and Deprivation*. Oxford University Press, Oxford, 1981.
- Sen, Amartya. Mortality as an Indicator of Economic Success and Failure. In *Innocenti Lectures*, Florence, Italy, 1995. UNICEF IFDC.
- Sen, Amartya. *Development as Freedom*. Oxford University Press, October 1999.
- Setel, Philip W; Macfarlane, Sarah B; Szreter, Simon; Mikkelsen, Lene; Jha, Prabhat; Stout, Susan, and AbouZahr, Carla. A Scandal of Invisibility: Making Everyone Count By Counting Everyone. *The Lancet*, 370:1569–1577, 2007.
- Setel, PW; Sankoh, O; Rao, C; Velkoff, VA; Mathers, C; Gonghuan, Y; Hemed, Y; Jha, P, and Lopez, AD. Sample Registration of Vital Events with Verbal Autopsy: a Renewed Commitment to Measuring and Monitoring Vital Statistics. *Bulletin of the World Health Organisation*, 83(8): 611–617, 2006.
- Shkolnikov, Vladimir M.; Cornia, Giovanni A.; Leon, David A., and Meslé, France. Causes of the russian mortality crisis: Evidence and interpretations. *World Development*, 26(11):1995 – 2011, 1998.
- Silva, Romesh. Child Mortality Estimation: Consistency of Under-Five Mortality Rate Estimates Using Full Birth Histories and Summary Birth Histories. *PLoS Med*, 9(8):e1001296, 08 2012.

- Sneeringer, Stacy E. Fertility Transition in Sub-Saharan Africa: A Comparative Analysis of Cohort Trends in 30 Countries. Technical report, ICF Macro, DHS Comparative Reports No. 23, Calverton, Maryland, 2009.
- Som, Ranjan Kumar. *Recall Lapse in Demographic Enquiries*. Asian Publishing House, New York, 1970.
- Spoorenberg, Thomas. Quality of age reporting : extension and application of the modified whipple's index. *Population (english edition)*, 62(4):729–741, 2007.
- Stanton, Cindy; Nouredine, Abderrahim, and Hill, Kenneth. DHS Maternal Mortality Indicators: An Assessment of Data Quality and Implications for Data Use. *Studies in Family Planning*, 31 (2):111–123, 2000.
- Sullivan, J.; Rutstein, S., and Bicego, G. Infant and Child Mortality. DHS comparative studies, no. 15, Macro International, 1994a.
- Sullivan, Jeremiah. Models for the Estimation of the Probability of Dying Between Birth and Exact Ages of Early Childhood. *Population Studies*, 26:79–98, 1972.
- Sullivan, Jeremiah; Rutstein, Shea Oscar, and Bicego, George T. Infant and Child Mortality. DHS Comparative Studies 15, Macro International Inc., Calverton, Maryland, 1994b.
- Swanson, D.; Siegel, J. S., and Shyrock, H. S. *The Methods and Materials of Demography*. Emerald Group Publishing, San Diego, CA and London, 2004.
- Szreter, Simon. The GRO and the Public Health Movement, 1837-1914. *Social History of Medicine*, 4:435 – 463, 1991.
- Timaeus, Ian. An Assessment of Methods for Estimating Adult Mortality From Two Sets of Data on Maternal Orphanhood. *Demography*, 23:435–450, 1986. ISSN 0070-3370. 10.2307/2061440.
- Timaeus, Ian. Estimation of Adult Mortality From Paternal Orphanhood: A Reassessment and a New Approach. *Population Bulletin of the United Nations*, 33:47–63, 1992.
- Timaeus, Ian M.; Zaba, B, and Ali, M. Estimation of Adult Mortality from Data on Adult Siblings. In Zaba, B. and Blacker, J.G.C., editors, *Brass Tacks: Essays in Medical Demography ; a Tribute to Professor William Brass*. Athlone Press, 2001.
- Tollman, Stephen; Kark, Sidney L., and Kark, Emily. The Pholela Health Centre: Understanding Health and Disease in South Africa Through Community-Oriented Primary Care. In Das Gupta, Monica; Aaby, Peter; Garenne, Michel, and Pison, Giles, editors, *Prospective Community Studies in Developing Countries*, pages 213–232. Clarendon Press, Oxford, 1997.

- Tollman, Stephen M; Kahn, Kathleen; Sartorius, Benn; Collinson, Mark A; Clark, Samuel J, and Garenne, Michel L. Implications of Mortality Transition for Primary Health Care in Rural South Africa: a Population-based Surveillance Study. *The Lancet*, 372(9642):893 – 901, 2008.
- Tran, Toan K.; Eriksson, BO; Nguyen, Chuc TK; Horby, Peter; Bondjers, Goran, and Petzold, Max. Dodalab: An Urban Health and Demographic Surveillance Site, the First Three Years in Hanoi, Vietnam. *Scandinavian Journal of Public Health*, 40(8):765–772, 2012.
- Trussell, James. A Re-estimation of the Multiplying Factors for the Brass Technique for Determining Children Survivorship Rates. *Population Studies*, 29(1):97–108, 1975.
- Trussell, James and Rodriguez, German. A Note on the Sisterhood Estimator of Maternal Mortality. *Studies in Family Planning*, 21(6):344–346, 1990.
- UNICEF, . *The Rights Start to Life. A Statistical Analysis of Birth Registration*. United Nations Children’s Fund, New York, 2005.
- UNICEF, . Multiple Indicator Cluster Survey (MICS 4) Questionnaire. Technical report, United Nations, 2009a.
- UNICEF, . Multiple Indicators Cluster Survey (MICS) Executive Directive. Technical Report Ex.Dir.CF/EXD/2009-002, United Nations, 2009b.
- UNICEF, WHO, The World Bank and UN Population Division, . Levels and Trends of Child Mortality in 2006: Estimates Developed by the Inter-agency Group for Child Mortality Estimation. Technical report, United Nations, New York, 2007.
- United Nations, . Universal Declaration of Human Rights (UDHR), 1948. Adopted 10 Dec. 1948, United Nations General Assembly Res. 217 A (III) (1948).
- United Nations, . International Covenant on Civil and Political Rights (ICCPR), 1966a. Adopted 16 Dec. 1966, G.A. Res. 2200 (XXI), U.N. GAOR, 21st Sess., Supp. No. 16, U.N. Doc. A/6316 (1966), 999 U.N.T.S. 171 (entered into force 23 Mar. 1976).
- United Nations, . International Covenant on Economic, Social and Cultural Rights (ICESCR), 1966b. Adopted 16 Dec. 1966, G.A. Res. 2200 (XXI), U.N. GAOR, 21st Sess., Supp. No. 16, U.N. Doc. A/6316 (1966), 993 U.N.T.S. 3 (entered into force 3 Jan. 1976).
- United Nations, . Convention on the Elimination of All Forms of Discrimination Against Women, 1979. Adopted 18 Dec. 1979, G.A. Res. 34/180, U.N. GAOR, 34th Sess., Supp. No. 46, U.N. Doc. A/34/46 (1980) (entered into force 3 Sept. 1981), 1249 U.N.T.S. 13, reprinted in 19 I.L.M. 33.



- United Nations, . *Model Life Tables for Developing Countries*, volume 77. Department of Economic and Social Affairs, United Nations, New York, 1982.
- United Nations, . Manual X: Indirect Techniques for Demographic Estimation. Technical report, United Nations Department of International Economic and Social Affairs, New York, 1983.
- United Nations, . Convention on the Rights of the Child, 1989. Adopted 20 Nov. 1989, G.A. Res. 44/25, U.N. GAOR, 44th Sess., Supp. No. 49, U.N. Doc. A/44/49 (1989) (entered into force 2 Sept. 1990), 1577 U.N.T.S. 3, reprinted in 28 I.L.M. 1448 (1989).
- United Nations, . Child Mortality Since the 1960s: A Database for Developing Countries. Technical report, United Nations, New York, 1992a.
- United Nations, . Child Mortality since the 1960s: A Database for Developing Countries. Technical report, United Nations, 1992b.
- United Nations, . *Handbook on Civil Registration and Vital Statistics Systems: Preparation of a Legal Framework*. UN Department of International Economic and Social Affairs Statistics Division, New York, 1998.
- United Nations, . United Nations Millennium Declaration. Resolution Adopted By The General Assembly [Without Reference to a Main Committee (a/55/1.2)] 55/2., 2000.
- United Nations, . *Principles and Recommendations for a Vital Statistics System*. United Nations Department of Economic and Social Affairs Statistics Division, New York, 2001. Revision 2.
- United Nations, . *Methods for Estimating Adult Mortality*. New York, NY., 2002. United Nations, Population Division, Department of Economic and Social Affairs.
- United Nations, . United Nations Coordination Meeting on the Estimation of Adult Mortality: Report of the Meeting. ESA/P/WP.211, 2008a. Population Division, Department of Economic and Social Affairs, United Nations.
- United Nations, . *Demographic Year Book 2008*. United Nations Statistics Division, 2008b. Series R, No. 39.
- United Nations, . *World Population Prospects: The 2008 Revision. Highlights*. United Nations, New York, 2009.
- United Nations, . *World Mortality Report 2011*. Population Division, Department of Economic and Social Affairs, 2012.
- United Nations Children's Fund, . *State of the World's Children 2011: Adolescence - An Age of Opportunity*, 2011.

- Van de Walle, Etienne. *The Multilingual Demographic Dictionary*. International Union for the Scientific Study of Population, Liege, 2nd edition edition, 1982.
- Waltisperger, Dominique and Mesle, France. Economic Crisis and Mortality: The Case of Antananarivo, 1976-2000. *Population*, 60:199–229, 2005.
- Waltisperger, Dominique; Cantrelle, Pierre, and Raljaona, Os{’ee. *La Mortalit{’e Ã Antananarivo de 1984-1995*. Number 7 in Documents et Manuels du CEPED. CEPED, Paris, 1998.
- Westoff, C.F. and Cross, A.R. The Stall in the Fertility Transition in Kenya. DHS Analytical Reports No. 9., 2006.
- Wilmoth, John; Canudas-Romo, Vladimir; Zureick, Sarah; Inoue, Mie, and Sawyer, Cheryl. A Flexible Two-dimensional Mortality Model For Use In Indirect Estimation. *Population Studies*, 66(1):1–28, 2012.
- Woodruff, Bradley A. Postscript on Measuring Mortality Rates in Cross-Sectional Surveys: a Commentary. *Field Exchange*, 17, November 2002.
- World Health Organization, ; UNICEF, ; UNFPA, , and The World Bank, . Trends in Maternal Mortality: 1990 to 2008. Technical report, United Nations, 2010.
- World Health Organization, ; UNICEF, ; UNFPA, , and The World Bank, . Trends in Maternal Mortality: 1990 to 2010. Technical report, United Nations, 2012.
- Wrigley, E.E.A. and Schofield, R.S. *The Population History of England, 1541-1871: a Reconstruction*. Cambridge Studies in Population, Economy and Society in Past Time Series. Cambridge University Press, 1989.
- Yang, Gonghuan; Hu, Jianping; Rao, Ke; Ma, Jeimin; Rao, Chalapati, and Lopez, Alan. Mortality Registration and Surveillance in China: History, Current Situation and Challenges. *Population Health Metrics*, 3(1):3, 2005. ISSN 1478-7954. doi: 10.1186/1478-7954-3-3.
- Ye, Yazoume; Wamukoya, Marilyn; Ezeh, Alex; Emina, Jacques, and Sankoh, Osman. Health and Demographic Surveillance Systems: a Step Towards Full Civil Registration and Vital Statistics System in sub-Sahara Africa? *BMC Public Health*, 12(1):741, 2012.
- Zaba, Basia and David, Patricia H. Fertility and the Distribution of Child Mortality Risk Among Women: An Illustrative Analysis. *Population Studies*, 50(2):pp. 263–278, 1996. ISSN 00324728.
- Zaslavsky, Allan M. Combining Census, Dual System, and Evaluation Study Data to Estimate Population Shares. *Journal of the American Statistical Association*, 88:1092–1105, 1993.

*BIBLIOGRAPHY*

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Zlotnik, Hania and Hill, Kenneth H. The use of hypothetical cohorts in estimating demographic parameters under conditions of changing fertility and mortality. *Demography*, 18(1):103–122, 1981.