The Own-Children Method of fertility estimation – the devil is in the detail

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Abstract

BACKGROUND

The Own-Children Method is a widely-used procedure for estimating levels, trends, and differentials in age-specific and total fertility from the age distribution.

OBJECTIVES

This article demonstrates that the procedure used in most applications of the Own-Children Method produces systematically biased estimates of the age-pattern of fertility and describes a new estimator that avoids this bias.

METHODS

The Own-Children Method incorporates an adjustment for the proportion of children by age who are not living with their mothers. Because these children include orphans and women's mortality accelerates with age, this adjustment over-estimates births to young women and under-estimates births to older women relative to the number of women in the denominators of the fertility rates. By explicitly estimating the prevalence of maternal orphanhood by age, one can instead calculate age-specific fertility using a formula that avoids this bias.

RESULTS

The bias in the estimated age-pattern of fertility is trivial for rates calculated from children born in the few years before an inquiry but increases with the age of the children and with the population's mortality. Its overall impact is to shift the fertility distribution toward younger ages at childbearing. Because the errors for women of different ages more-or-less cancel, the bias in estimates of total fertility is smaller.

CONTRIBUTION

The new Own-Children Method estimator of age-specific fertility proposed here eliminates a small but systematic bias in the results produced by the existing procedure. It should enable analysts using the Own-Children Method to measure fertility more accurately in the future.

KEYWORDS: reverse survival; age-specific fertility; indirect estimation; census analysis

1. Background

The Own-Children Method of estimation is a procedure for estimating age-specific and total fertility in the period prior to a census or survey from the age distribution of the population. Early versions of the method were described in the 1960s (Grabill and Cho 1965), and a detailed reference guide to it was produced in the 1980s (Cho, Retherford and Choe 1986). The method provides a way of producing time series of fertility estimates from single-round studies that did not collect full birth histories. Equally, because it can be applied to large-scale inquiries, such as national censuses, the method is of value for high-resolution studies of differential fertility. It has been used in a wide range of applications. These include the estimation of fertility levels and trends in both less developed countries (e.g., Avery et al. 2013, Retherford et al. 2005) and historical populations (e.g., Breschi, Kuroso and Michel 2003, Hacker 2003, Reid et al. 2019) and the investigation of differential fertility in the developed world (e.g., Abbasi-Shavazi and McDonald 2000, Dubuc 2009).

2. Objectives

This article demonstrates that the procedure used in most applications of the Own-Children Method produces systematically biased estimates of the age-pattern of fertility and describes a new estimator that makes different assumptions about the population which avoid the source of the bias.

3. Methods

The Own-Children Method is based on the idea of reverse survival, that children aged any age x are the survivors of births that occurred x to x+1 years previously. Stated formally,

$$B(t-x) = \frac{C_x^*(t)}{L_x}$$

where $B(t)$ represents births at time t to t–1, $C_x^*(t)$ represents children aged x in completed years at time t, and L_x represents survivors aged x in the life table for the cohort.[1]

[1] In order to simplify the notation, this article assumes throughout that mortality is constant and that the radix of the life table, l_0, is 1. The method can readily be elaborated to deal with changing mortality.

By reverse surviving both the children and adult female members of the current population to the time when the children were born, one can calculate a series of estimates of the General Fertility Rate for successive years prior to the inquiry. For single years of age

$$GFR(t-x)=\frac{\dfrac{C_x^*(t)}{L_x}}{\sum_a W_a(t)\dfrac{L_{a-x-0.5}^f}{L_{a-0.5}^f}}$$

where $W_a(t)$ represents women aged a at t and the superscript f indicates a life table for women.

One can also estimate total fertility by reverse survival if one uses indirect standardisation (Timæus and Moultrie 2013). All that is required is to apply a standard fertility distribution appropriate to the population under study to the reverse-survived population of women by age in each earlier year to calculate expected births. If the standard distribution has been normalised to sum to one, total fertility can be estimated as the ratio of the observed number of reverse-survived births each year to the expected number calculated using the standard distribution.

If one can link children to their mothers when they are living in the same household, the reverse-survival procedure can be extended to estimate age-specific fertility using the Own-Children Method

$$f_{a-x}(t-x)=\frac{\dfrac{C_{x,a}(t)}{L_x}}{W_a(t)\dfrac{L_{a-x-0.5}^f}{L_{a-0.5}^f}} \tag{1}$$

where Cho, Retherford and Choe (1986:8) define $C_{x,a}(t)$ as the own children aged x of women aged a enumerated in a census conducted at time t.

Unfortunately, there is a problem embedded in this plausible looking equation with either Cho, Retherford and Choe's (1986) definition of $C_{x,a}(t)$ or their description of the Own-Children Method. Only living women can be enumerated in an inquiry. Cho, Retherford and Choe (1986:9) argue that, assuming that $C_{x,a}(t)$ has been adjusted for unmatched children, it represents the survivors of the births occurring x years earlier to women aged a–x at that time

$$C_{x,a}(t)=B_{a-x}(t-x)L_x$$

where $B_a(t)$ is the number of births to women aged a at time t. This equation only balances, however, if $C_{x,a}(t)$ represents all surviving children in the population, not just those whose mothers are also alive. Thus, if we retain Cho, Retherford and Choe's definition of $C_{x,a}(t)$ as the surviving children of women who have also survived to be enumerated at time t, they are

$$C_{x,a}(t) = B_{a-x}(t-x)L_x \frac{L^f_{a-0.5}}{L^f_{a-x-0.5}}$$

and

$$f_{a-x}(t-x) = \frac{\dfrac{C_{x,a}(t)}{L_x}\dfrac{L^f_{a-x-0.5}}{L^f_{a-0.5}}}{W_a(t)\dfrac{L^f_{a-x-0.5}}{L^f_{a-0.5}}} = \frac{C_{x,a}(t)}{L_x \cdot W_a(t)}. \qquad (2)$$

The survivorship ratios for the women drop out of the equation because, in contrast to the basic reverse-survival method, the numerator of (2) only includes children that have been linked to a living mother who appears in the denominators of the rates, not all children.

Expressing the Own-Children Method in this way emphasises that it cannot provide estimates of the fertility of dead women with unknown ages who cannot be linked to their children. It can only be used to estimate the fertility of survivors. Whether the fertility of surviving women is representative of the fertility of all women who were alive at some earlier date cannot be determined from the internal evidence provided by a single-round inquiry.

Equation (2) seems to suggest that instead of adjusting the observed counts of women and births for women's mortality, one can simply calculate fertility rates from data on surviving women and their children. In fact, the calculations are necessarily more complex than this because one is usually unable to determine $C_{x,a}(t)$ directly. Some children with living mothers do not live with their mother and no way usually exists to distinguish such children from maternal orphans who can never coreside with their mother. One can only do this if the inquiry asked explicitly about the survival of individuals' mothers.

Let $V^*_{a,x}(t)$ be the proportion of children aged x with living mothers aged a who live with their mothers and $V_{a,x}(t)$ the proportion of *all* children aged x born to women who were then aged a–x who live with their mother, so that

$$V_{a,x}(t) = \frac{B_{a-x}(t)L_x V^*_{a,x}(t)\dfrac{L^f_{a-0.5}}{L^f_{a-x-0.5}}}{B_{a-x}(t)L_x\left(V^*_{a,x}(t)\dfrac{L^f_{a-0.5}}{L^f_{a-x-0.5}} + \left(1-V^*_{a,x}(t)\right)\dfrac{L^f_{a-0.5}}{L^f_{a-x-0.5}} + \left(1-\dfrac{L^f_{a-0.5}}{L^f_{a-x-0.5}}\right)\right)} = V^*_{a,x}(t)\frac{L^f_{a-0.5}}{L^f_{a-x-0.5}}. \qquad (3)$$

The three groups of children in the denominator of the first expression for $V_{a,x}(t)$ comprise non-orphans who live with their mothers, non-orphans who do not live with their mother, and maternal orphans, respectively. They therefore sum to one. Then, if $C_{x,a}(t)$ is defined as denoting own children who *coreside* with their mother and can therefore be linked to her (implying that both the mother and her child are alive), one obtains

$$f_{a-x}(t-x) = \frac{\dfrac{C_{x,a}(t)}{L_x \cdot V^*_{a,x}(t)} \dfrac{L^f_{a-x-0.5}}{L^f_{a-0.5}}}{W_a(t)\dfrac{L^f_{a-x-0.5}}{L^f_{a-0.5}}} = \frac{\dfrac{C_{x,a}(t)}{L_x \cdot V_{a,x}(t)}}{W_a(t)\dfrac{L^f_{a-x-0.5}}{L^f_{a-0.5}}}.$$

The survivorship ratio for women reappears in the denominator of the righthand side of this equation because dividing the own children by $V_{a,x}(t)$ reintroduces the orphans into its numerator in addition to children who have living mothers but do not co-reside with them.

It is also impossible to use this equation to estimate age-specific fertility from most inquiries, however, because one could only determine $V_{a,x}(t)$ for each a if one knew the ages of the mothers of all children, not just linked children. Instead, all that is known in practice is $V_x(t)$, the overall proportion of children aged x who have been linked to their mother. However, by substituting $V_x(t)$ for $V_{a,x}(t)$ in the previous equation, one obtains an elaboration of (1) that adjusts for unlinked children. This is the formulation of the Own-Children Method that is actually used both by Cho, Retherford and Choe (1986) and in most other applications of the Own-Children Method

$$f_{a-x}(t-x) \approx \frac{\dfrac{C_{x,a}(t)}{L_x \cdot V_x(t)}}{W_a(t)\dfrac{L^f_{a-x-0.5}}{L^f_{a-0.5}}}. \qquad (4)$$

Equation (4) avoids the inconsistencies in (1) because $V_x(t)$ includes both orphans and other unlinked children, bringing the numerators and the denominators of the rates into correspondence. Although, Cho, Retherford and Choe (1986) define own children as all living children, including maternal orphans, in practice they work with children who can be linked to their living mothers and inflate their numbers to allow for non-coresident children. The procedure adjusts for the non-coresident children with living mothers and the maternal orphans simultaneously (together with any linkage failures, as these cannot be distinguished from genuine non-coresident children). The adjustment to the numerator depends only on the children's age and involves the assumption that the distribution of the ages of the mothers of non-coresident children matches that of the mothers of own children.

Thus, the standard Own-Children Method for estimating fertility applies the same adjustment for non-coresident children to the linked children whatever the age of their mothers. Unfortunately, it is unlikely that $V_x(t)$ is a good approximation for $V_{a,x}(t)$ for all a because many of the children who are not living with their mother are maternal orphans and women's mortality increases sharply with age. The assumption that the proportion of children of a given age who live with their mothers is unrelated to their mother's age systematically distorts the age pattern of fertility by overestimating the fertility of younger women ($V_x < V_{a,x}$ and so over-inflates $C_{x,a}$) and underestimating the fertility of older women ($V_x > V_{a,x}$ and so under-inflates $C_{x,a}$).

This limitation of the Own-Children Method arises, not because (4) fails to take maternal orphanhood into account, but because the adjustment that it makes for orphanhood is not a very good one. Thus, at the end of their explanation of the basic Own-Children method, Cho, Retherford and Choe (1986:17) go on to suggest that, if one knows which children are orphans, the estimates can be improved if one inflates the numerators by $1/V_x^*(t)$, not $1/V_x(t)$. However, if one replaces $V_x(t)$ in (4) with the integral over a of the righthand of (3), the survivorship ratios for women cancel out. Thus, if one adjusts by $V_x^*(t)$, one should *not* rejuvenate the numbers of women exposed to risk in the denominators of the rates. This last point is not made clear by the existing literature.

Integrating (3) over all ages of mother also serves to elucidate the precise link between the numbers of children that cannot be linked to their mothers and the number of orphans

$$V_x(t) = \int V_{a,x}(t)da = \int \frac{B_{a-x}(t-x)V_{a,x}^*(t)\dfrac{L_{a-0.5}^f}{L_{a-x-0.5}^f}}{B_{a-x}(t-x)} da = S_x(t)\int V_{x,a}^*(t)da \approx S_x(t)V_x^*(t)$$

where $S_x(t)$ is the overall proportion of children aged x whose mother is alive (Brass and Hill 1973). $S_x(t)$ is simply a weighted average of the probabilities of surviving of mothers of different ages at the time when they gave birth, with the weights being the proportion of births born to women of each age

$$S_x(t) = \int \frac{B_{a-x}(t-x)\dfrac{L_{a-0.5}^f}{L_{a-x-0.5}^f}}{B_{a-x}(t-x)} da .$$

Thus, if we adjust $V_x(t)$ by $S_x(t)$, estimating fertility involves only the assumption that the probability that an *unorphaned* child lives with his or her mother is independent of her age, rather than the assumption that the probability of all unlinked children living with their mother is unrelated to her age. This alternative assumption is evidently less restrictive than the existing one. The resulting adjustment factors for converting the ratios of the own children to the women into fertility rates depend only on *x,* the age of the children, not on the age of the mothers

$$f_{a-x}(t-x) = \frac{\dfrac{C_{x,a}(t)}{L_x \cdot V^*_{a,x}(t)} \dfrac{L^f_{a-x-0.5}}{L^f_{a-0.5}}}{W_a(t)\dfrac{L^f_{a-x-0.5}}{L^f_{a-0.5}}} \approx \frac{\dfrac{C_{x,a}(t)}{L_x \cdot V^*_x(t)}}{W_a(t)} = \frac{C_{x,a}(t)}{W_a(t)} \frac{S_x(t)}{L_x \cdot V_x(t)}. \qquad (5)$$

This formulation of the Own-Children Method is obtained by extending (2), rather than (1), to allow for unlinked children. It brings the numerators and denominators of the fertility rates into correspondence by eliminating orphaned children from the numerator, instead of by augmenting the denominator with women who have died since they gave birth.

Figure 1 Proportion of surviving children living with their mother according to her age group by age group of her child, nine Demographic and Health Surveys

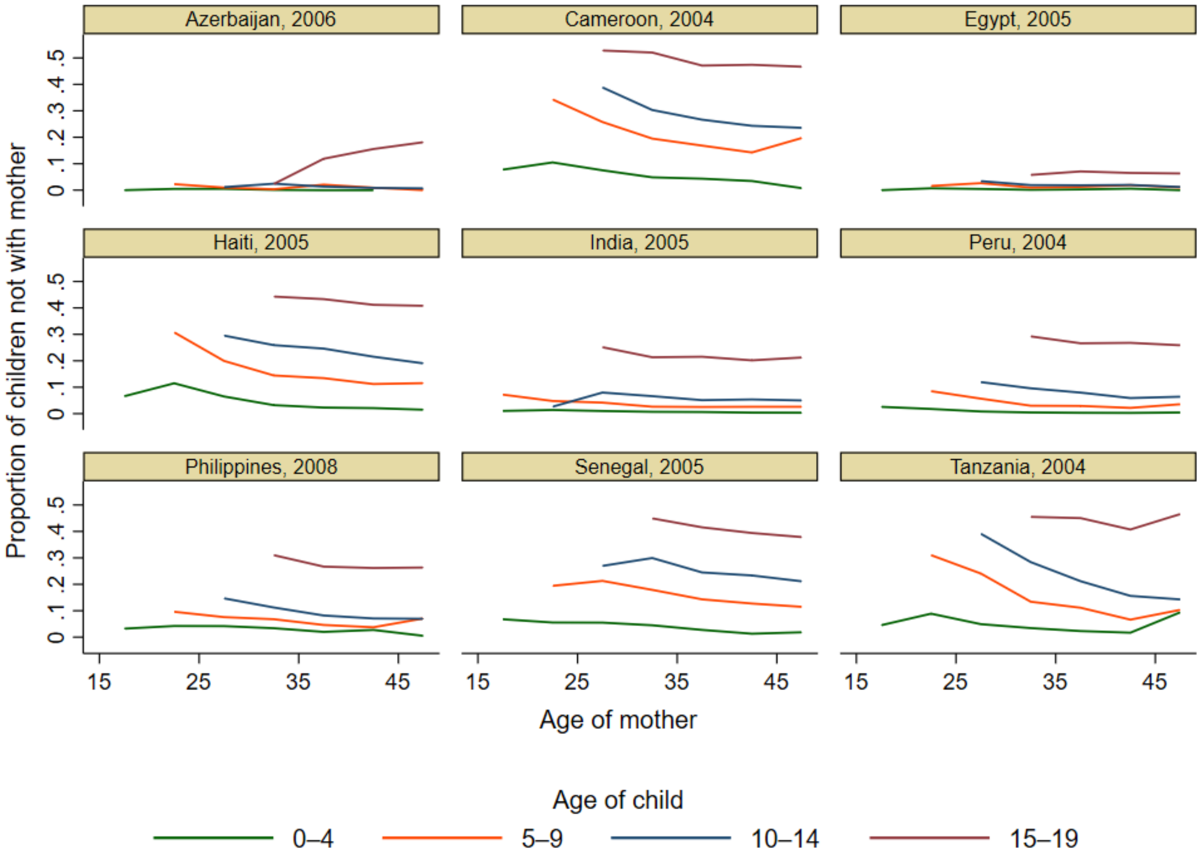


Figure 1 uses Demographic and Health Surveys (DHS) birth history data in which the ages of both the women and all their children are known to examine the assumption that the proportion of children who are living with their mother is unrelated to her age in nine countries. The assumption appears to hold up in most of them, particularly for younger children. It is least realistic for children aged 5–14 in Tanzania where, the younger the woman, the less likely her children are to live with her. In contrast, the proportion of children who have been orphaned rises with the age of their mother. Thus, in a country like Tanzania, $V_x(t)$, which is based on both these groups of children, may vary less with mother's age than $V_x^*(t)$. In most contexts, however, estimates made with (5) will be more accurate than those made using (4).

The proportion of children with living mothers, $S_x(t)$, can be obtained by asking the question "Is this child's mother alive?" As Cho, Retherford and Choe (1986) point out, some inquiries include this question. For example, DHS household surveys usually ask it for children aged less than 15. Tabulated by five-year age group, it is the measure used in the estimation of adult women's mortality from orphanhood data (Brass and Hill 1973).

Table 1 Coefficients for estimating the proportion of children aged *x* with living mothers (S_x) from life table survivorship from exact age 25 to age *x*+25

$$S_x = \beta_0 + \beta_1 \bar{M} + \beta_2 L_{x+25}/l_{25}$$

Age (x)	β_0	β_1	β_2	Age (x)	β_0	β_1	β_2
0	0.124	–0.00006	0.877	19	–0.016	–0.00407	1.123
1	0.010	–0.00018	0.995	20	–0.006	–0.00448	1.124
2	–0.013	–0.00030	1.021	21	0.005	–0.00492	1.124
3	–0.025	–0.00042	1.037	22	0.016	–0.00539	1.124
4	–0.037	–0.00053	1.051	23	0.030	–0.00589	1.123
5	–0.045	–0.00065	1.063	24	0.045	–0.00643	1.121
6	–0.051	–0.00079	1.072	25	0.061	–0.00699	1.119
7	–0.054	–0.00093	1.079	26	0.078	–0.00759	1.116
8	–0.055	–0.00109	1.085	27	0.098	–0.00823	1.112
9	–0.056	–0.00126	1.090	28	0.118	–0.00890	1.107
10	–0.057	–0.00145	1.095	29	0.141	–0.00961	1.102
11	–0.056	–0.00166	1.100	30	0.165	–0.01035	1.095
12	–0.054	–0.00189	1.104	31	0.190	–0.01113	1.087
13	–0.051	–0.00213	1.107	32	0.217	–0.01194	1.078
14	–0.047	–0.00240	1.110	33	0.246	–0.01278	1.068
15	–0.043	–0.00268	1.114	34	0.276	–0.01366	1.057
16	–0.038	–0.00299	1.117	35	0.307	–0.01456	1.045
17	–0.032	–0.00333	1.119	36	0.339	–0.01548	1.032
18	–0.024	–0.00369	1.121	37	0.372	–0.01641	1.018

Alternatively, if the inquiry has not collected these data, one can estimate $S_x(t)$ from any life table by 'reversing' the orphanhood method for estimating adult mortality (Timæus 1992, 2013). The only further information required is an estimate of $\bar{M}$, the mean age at which women give birth. Table 1 presents coefficients estimated from a comparable set of simulated populations to that used to derive the orphanhood method.[2] It extends up to age 37 in order to include all possible children of women aged less than 50.

4. Results

Do the approximations that are buried in the derivation of the Own-Children Method matter? Certainly, in that we ought to understand the theoretical basis of our demographic estimates, any assumptions that are required to make them, and the implications of those assumptions. But do they matter numerically? That depends on what is being measured. It is of little importance for recent estimates of fertility made by the Own-Children Method from data on children aged less than 5. The established estimator and the one proposed here give virtually identical results. For older children, however, the differences between the fertility rates produced using the two estimators are larger.

Apart from age of the children, the amount of bias in estimates made using the existing method will depend on the relative number of orphans and non-orphans among children who are not living with their mothers and on age pattens of fertility and mortality in the population. On the other hand, while the method for estimating maternal orphanhood encapsulated in the coefficients in Table 1 is a very well-established and robust one, it may produce somewhat biased results in populations with highly unusual age patterns of fertility and mortality. However, all the terms in (4) and (5) cancel except for women's survivorship since the birth of their children in (4) and the proportion of children that are orphaned by age in (5). Thus, by comparing the ratio of these statistics, one can quantify the gains in accuracy that will result from using the new estimator if the assumption holds that $V^{*}_{a,x}(t)$ is constant over women's age, a, for a fixed age of child, x.

Given this assumption, for children aged 10–14, at a life expectancy at birth (e_0) of 50 years, one would expect the existing estimator to exaggerate the fertility of teenage girls by 2–3%, depending on the timing of fertility (because fewer of their children have been orphaned than is indicated by V_x), but to underestimate the fertility of women in their forties by 10% (because, as fewer of the children's mothers survive than V_x implies, the numerator is not inflated sufficiently). At e_0 = 65 years, the biases for the young and older women drop to

[2] The models and procedure involved in simulating the relationship between women's survivorship and orphanhood are described by Timæus (1992). However, the coefficients presented here are based on 480 simulated populations, rather than the 96 modelled in the late-1980s, including an additional subset of populations with lighter mortality than any of those in the original analysis. The code is available on GitHub (github.com/BugBunny/oRphanhood).

1–2% and 5% respectively and, when e_0 = 80 years, they are only about 1% for both age ranges. The biases in estimates of fertility for the more distant past (i.e., if one makes use of the data on children aged 15 or more) will usually be considerably larger. At all levels of mortality, the biases in the estimates of age-specific fertility for young and older women largely cancel and the existing Own-Children Method estimator should produce estimates of total fertility that are within 2% of its actual value for the 15 years before an inquiry.

Figure 2 presents own-children estimates of age-specific fertility for five-year periods prior to two successive censuses of the same country based for each census on the numbers of children aged 2–21 years by single years of age. The estimates were made using IPUMS microdata from the 1900 (5% sample) and 1910 (1% sample) censuses of the United States (Ruggles *et al*. 2021) and the 2000 and 2010 censuses (10% samples) of Zambia (Minnesota Population Center 2021). The figure compares estimates produced using the new estimator with those from the conventional ('old' in the key for brevity) estimator. For the United States, the assumptions made about mortality were based on indirect estimates calculated from women's reports on their children ever-born and dead children in the two censuses (Hill 2013). Zambia was experiencing a severe HIV epidemic during the period under consideration and the assumptions made about the mortality of the children and their mothers were based on UN Population Division (2019) estimates that reflect this.

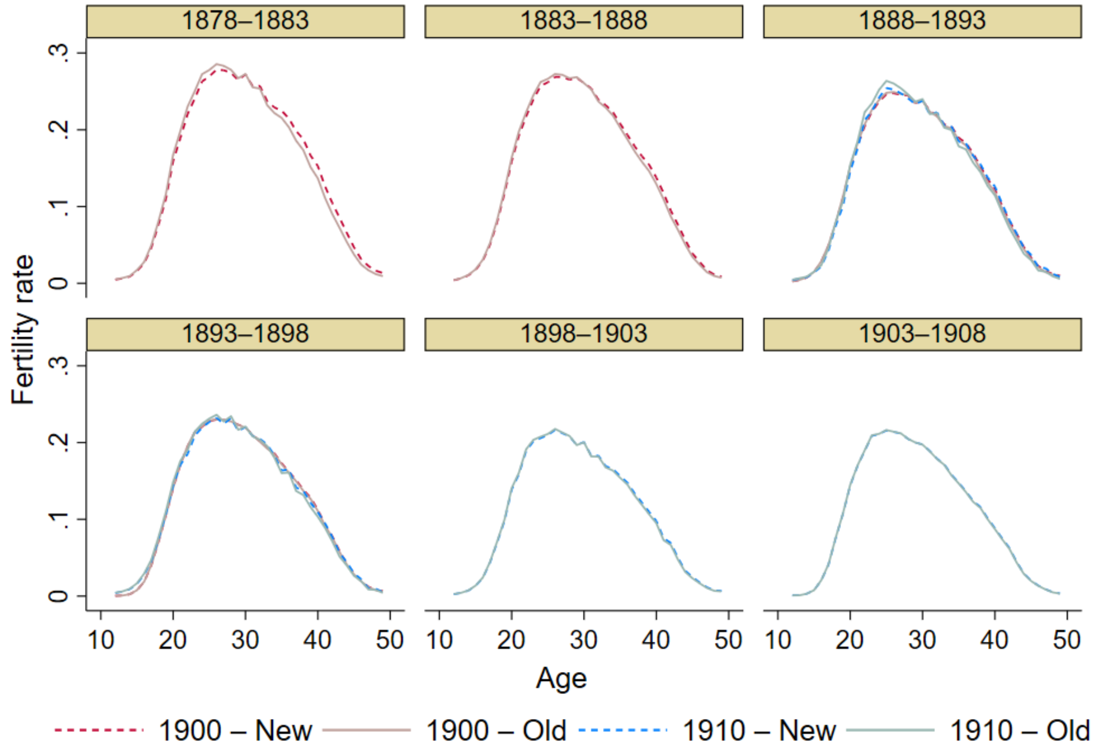
The results from the two applications are similar. In both countries the two estimators produced very similar results from data on children aged 2–11, However, for children aged 12–21 the new estimator yields fertility distributions that are shifted rightward, toward older ages than the distributions produced by the conventional estimator. In both countries, the estimates made from data on children aged 12–21 in the later census cover the same two periods as the estimates made from data on children aged 2–11 in the earlier census. In those periods, the new estimates based on children aged 12–21 in the later census agree more closely than those from the conventional estimator with the estimates based on children aged 2–11 in the earlier census. This pattern of results is consistent with the conclusion that the conventional estimator underestimates the ages at which women bear children increasingly severely as one moves back in time and that the new estimator avoids this systematic bias.

5. Conclusions

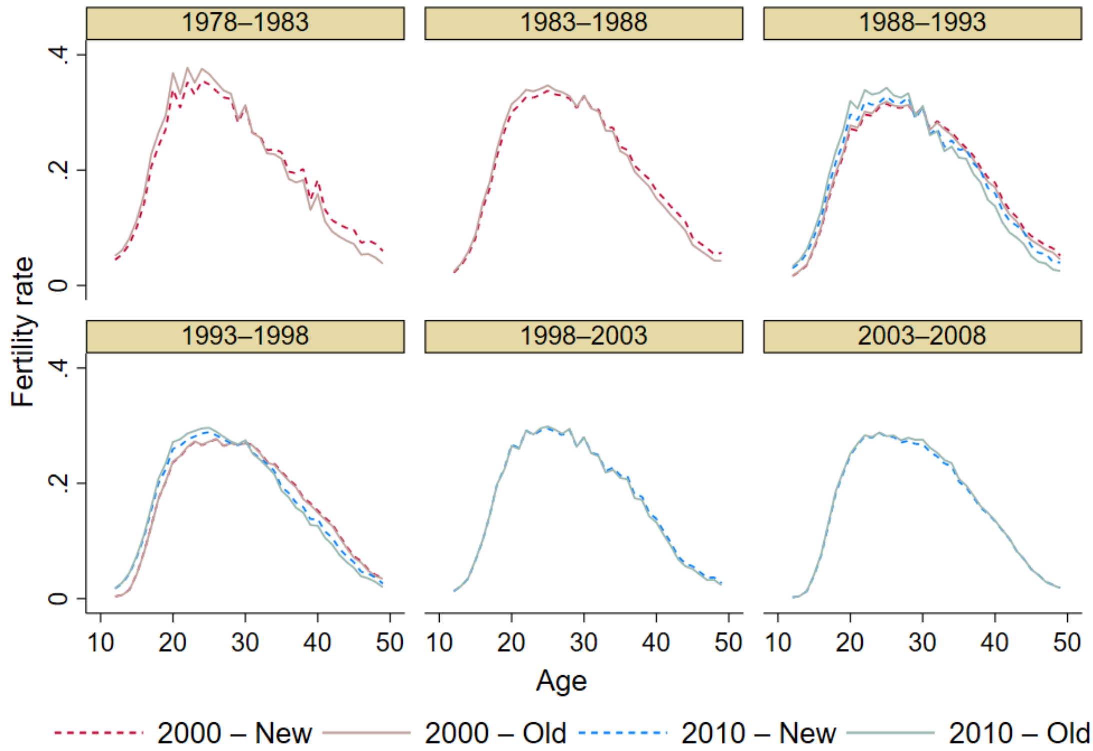
The Own-Children Method is a widely-used method for estimating fertility from the age distribution of the population. It makes it possible to study fertility using censuses and

Figure 2 Own-children estimates of age-specific fertility for five-year periods prior to successive national censuses made using the old (Cho, Retherford and Choe 1986) and new adjustments for orphaned children

a. United States of America, 1900 and 1910 Censuses



b. Zambia, 2000 and 2010 Censuses



surveys that that asked few or no questions about the topic. The main advantage of the full Own-Children Method over simpler reverse-survival methods of estimating fertility is that linking individual children to their mothers enables one to estimate age-specific fertility.

Research conducted in the 1980s (Retherford and Alam 1985, Cho, Retherford and Choe 1986) suggested that the Own-Children Method often produces estimates of age-specific and total fertility that approach the quality of those calculated from full birth histories. Series of estimates of both types are vulnerable to distortions resulting from misreporting of children's ages and dates of birth, but the severity of these errors is usually similar in the two series.

It may be, however, that this assessment was over-generous to the conventional Own-Children Method estimator. Most fertility surveys, including the World Fertility Survey and Demographic and Health Surveys, only collect birth histories from women aged less than 50. This means that estimates of fertility made from them for the period before the survey become increasingly truncated by age as one moves back in time from the date of data collection. By 15 years before the date of the inquiry, no estimates can be made of fertility at ages 35 or more. Thus, the 1980s research just referenced focused on comparing the own-children and birth history estimates of age-specific fertility below age 35 and cumulative fertility by age 35. As a result, these studies failed to detect that the existing Own-Children Method of estimating fertility performs poorly for the righthand tail of the age-specific fertility distribution, tending to produce underestimates of fertility.

This paper proposes an improvement upon the existing Own-Children Method of estimating fertility from data on children's ages that involves explicitly removing orphaned children from the numerators of the rates. This approach is conceptually clearer than the existing one in that it emphasizes that the retrospective reports of living women can never provide information on the fertility of women who have died. It is also somewhat computationally less burdensome than the existing method as the adjustment depends only on the children's ages, rather than requiring a different series of adult survivorship ratios to be applied to the age-specific rates calculated for each cohort of mothers. In most countries, the proportion of women's living children who live apart from them varies little by their mother's age for children of any given age. Therefore, adopting the new estimator proposed here will avoid the systematic distortions in estimates of the age pattern of fertility produced by the existing method.

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