Maternal cumulative prevalence measures of child mortality show heavy burden in sub-Saharan Africa

Emily Smith-Greenaway[a,1] and Jenny Trinitapoli[b]

[a]Department of Sociology, University of Southern California, Los Angeles, CA 90089; and [b]Department of Sociology, University of Chicago, Chicago, IL 60637

Edited by Patrick Clement Heuveline, University of California, Los Angeles, CA, and accepted by Editorial Board Member Mary C. Waters January 2, 2020 (received for review April 30, 2019)

We advance a set of population-level indicators that quantify the prevalence of mothers who have ever experienced an infant, under 5-y-old child, or any-age child die. The maternal cumulative prevalence of infant mortality (mIM), the maternal cumulative prevalence of under 5 mortality (mU5M), and the maternal cumulative prevalence of offspring mortality (mOM) bring theoretical and practical value to a variety of disciplines. Here we introduce maternal cumulative prevalence measures of mortality for multiple age groups of mothers in 20 sub-Saharan African countries with Demographic and Health Surveys data spanning more than two decades. The exercise demonstrates the persistently high prevalence of African mothers who have ever experienced a child die. In some African countries, more than one-half of 45- to 49-y-old mothers have experienced the death of a child under age 5, and nearly two-thirds have experienced the death of any child, irrespective of age. Fewer young mothers have experienced a child die, yet in many countries, up to one-third have. Our results show that the mIM and mU5M can follow distinct trajectories from the infant mortality rate (IMR) and under 5 mortality rate (U5MR), offering an experiential view of mortality decline that annualized measures conceal. These measures can be adapted to quantify the prevalence of recurrent offspring mortality (mROM) and calculated for subgroups to identify within-country inequality in the mortality burden. These indicators can be used to improve current understandings of mortality change, bereavement as a public health threat, and population dynamics.

child mortality | sub-Saharan Africa | bereavement

Dramatic reductions in the infant mortality rate (IMR) and under 5 mortality rate (U5MR) over the past half-century are among the global health community's most notable achievements (1). The trends are clear, and the message is positive: the world today is healthier and safer for young people than ever before.

Sub-Saharan African countries have experienced some of the swiftest reductions in the IMR and U5MR (2). However, the all-time low IMRs and U5MRs conceal the pervasiveness with which contemporary populations experience children die. The IMR and U5MR provide annualized snapshots of a population's mortality regime; these measures are, by design, amnesiac to any legacy of higher mortality. Yet, African mothers today had children under higher mortality conditions, and these conditions persist in surviving mothers' lives. Moreover, because each live birth exposes mothers to the risk of a child dying, high fertility multiplicatively increases African mothers' lifetime likelihood of experiencing a child's death. The clustering of deaths among siblings in high-mortality countries is well documented (3), yet we lack population-level measures that summarize the mortality burden from the perspective of parents.

We present population-level mortality measures that estimate the proportion of mothers in a population who have experienced the loss of a child. Specifically, we calculate the cumulative prevalence of mothers who have ever experienced an infant death, the death of a child under age 5, or the death of a child of any age (i.e., offspring mortality) for distinct age groups of mothers in 20 sub-Saharan African countries over two decades. We express these estimates per 1,000 mothers and term them as follows: the maternal cumulative prevalence of infant mortality (mIM), the maternal cumulative prevalence of under 5 mortality (mU5M), and the maternal cumulative prevalence of offspring mortality (mOM). By comparing the mIM and mU5M with their orthodox counterparts, the IMR and U5MR, we demonstrate that the mIM and mU5M can follow trajectories that deviate from the annualized measures. The mOM summarizes high levels of mortality among older children and adolescents. Each indicator can be expanded to estimate recurrent offspring mortality (mROM), or it can be tailored to particular subpopulations and used to evince within-country inequality in the mortality burden. Maternal cumulative prevalence indicators offer an experiential view of how annualized mortality rates are manifest in the lives of ordinary mothers.

Quantifying mothers' experiences of child death is valuable for at least three reasons. First, these estimates offer evidence that can shape our understanding of global inequality. Recent scholarship from high-income settings identifies death in one's family as an underappreciated source of social inequality (4, 5). The death of a child, in particular, is a major life stressor with long-term consequences (6).

Significance

Over the past half-century, infant and under 5 mortality rates have fallen worldwide, reaching all-time low levels. Even so, in many low-income settings, the death of a child remains a common parental experience. To quantify the burden of mortality from a new perspective, we generate population-level mortality indicators that estimate the prevalence of mothers who have ever experienced an infant, under 5-y-old child, or any-age child die. The maternal cumulative prevalence of infant mortality, under 5 mortality, and offspring mortality show that, in many contemporary African settings, a majority of mothers have experienced the death of at least one child. These indicators enhance our understanding of the levels and distributions of the mortality burden.

Author contributions: E.S.-G. and J.T. designed research; E.S.-G. performed research; E.S.-G. analyzed data; and E.S.-G. and J.T. wrote the paper.

The authors declare no competing interest.

This article is a PNAS Direct Submission. P.C.H. is a guest editor invited by the Editorial Board.

Data deposition: All data replication files from this article are posted at Harvard Dataverse (https://doi.org/10.7910/DVN/3FGPTM).

See online for related content such as Commentaries.

[1]To whom correspondence may be addressed. Email: smithgre@usc.edu.

This article contains supporting information online at https://www.pnas.org/lookup/suppl/doi:10.1073/pnas.1907343117/-/DCSupplemental.

First published February 10, 2020.

In the West, bereaved parents are at elevated risk of serious and persistent psychological problems (7–9), physical health deterioration (7, 10, 11), and relationship strain (7). The generalizability of these results to African contexts is unknown, but select studies similarly conclude that bereaved mothers in sub-Saharan Africa are vulnerable in myriad ways. Even where mothers are accustomed to and skilled at navigating uncertain environments (12), a child's death can lead to guilt and blame, stigma, stress, and relationship strain (13–17).

Second, clarifying the burden of child death among mothers has theoretical significance for understanding population change (18–20). Demographic transition theory links declining death rates, driven primarily by reductions in the IMR and U5MR, to subsequent declines in birth rates (21–24). A presumed bridge between these processes is mothers' experience of child mortality—both personal experience and what women witness among the mothers around them (25–28). Even as microlevel studies show that women's observations of mortality in their networks and communities inform their child mortality perceptions, their fertility desires, and related behaviors (27–32), the link between the IMR and fertility is weak at the macrolevel (33, 34). Mother-centered measures of child mortality may better operationalize an average woman's mortality perceptions and thus, more accurately estimate the relationships between a population's mortality conditions and women's fertility behaviors.

Third, mother-centered measures facilitate a shift from the global community's intensive focus on under 5 mortality and consider child deaths more comprehensively. The prioritization of infant and child survival in sub-Saharan Africa is warranted. Yet, childhood, adolescent, and young-adult mortality rates are also high across the region (35). The region's mortality conditions are so harsh that there is a unique pattern of positive health selection into adulthood—unlike other world regions, only the healthiest survive in Africa (36). Mortality conditions at age 6 and beyond suggest that a sizeable proportion of mothers will experience older children or adolescents die.

Materials and Methods

To construct the maternal cumulative prevalence indicators, we use Demographic and Health Surveys (DHS) data from 20 sub-Saharan African countries.* *SI Appendix*, Fig. S1 provides a list of countries, survey years, and analytic sample sizes.

Our calculations are based on women who have ever had a child beginning with the mIM: the prevalence of mothers who have experienced the death of at least one infant. We sum the number of mothers who had a child die before age 1 among those who ever had a live birth and express this per 1,000 mothers. We calculate these indicators separately for women of reproductive age (20 to 44 y old) and those completing their reproductive years (45 to 49 y old). Note that we exclude mothers younger than 20 y old from our primary analyses but report estimates of the mIM among 15- to 19-y-old mothers in *SI Appendix*, Fig. S2.[†]

In supplementary analyses, we disaggregate mothers into 5-y age groups (20 to 24, 25 to 29, 30 to 34, 35 to 39, 40 to 44) to explore differences by age and cohort (*SI Appendix*, Figs. S3 and S4).

Next, to estimate the mU5M, we do the same for mothers who have ever had a child die before reaching age 5. Comparisons with the IMR and U5MR rely on published DHS estimates (37). Finally, we estimate mothers' experience of offspring mortality (mOM): that is, the prevalence of mothers who have experienced a child death, regardless of the child's age at the time of death. We calculate the mOM for 45- to 49-y-old mothers and extend the measure to estimate the cumulative prevalence of mROM among this same age group.

Maternal cumulative prevalence indicators are susceptible to three measurement concerns. First, estimates are based on self-reports, which tend to undercount deaths. Our estimates are thus conservative, especially for older mothers who tend to provide incomplete data (38). Because we use the same data source to generate IMRs and U5MRs, this bias applies equally to these measures.

Second, some of the world's highest maternal mortality rates are in sub-Saharan Africa (39), and our estimates omit deceased mothers who may have experienced higher levels of offspring mortality than surviving mothers. Survivor bias will also lead to conservative estimates. Moreover, because HIV/AIDS causes joint maternal–child deaths, our estimates may be especially conservative in countries with severe HIV epidemics.

Third, the maternal cumulative prevalence indicators are subject to multiple sources of censoring and are sensitive to the fertility conditions (e.g., age at first birth, fertility rate, birth spacing) that characterize each country-year. To address the biases introduced by one type of censoring, in supplementary analyses we adopted a probability-based approach, wherein we adjust for variation in the duration of motherhood (i.e., exposure) using the inverse of the Kaplan–Meier survivor function to estimate the probability of a mother experiencing an infant, under 5-y-old child, or any-age child die by a specific age. Mothers begin the hazard at the year of first birth and fail when they experience an infant, under 5-y-old child, or any-age child die. This approach produces slightly higher estimates for mothers age 20 to 44[‡] and almost identical estimates for mothers age 45 to 49 (results available at Harvard Dataverse, https://doi.org/10.7910/DVN/3FGPTM; ref. 40.), confirming that the simple proportions provide accurate but conservative estimates of the cumulative burden of child death on mothers.

Results

Fig. 1 depicts trends in the mIM among reproductive-age mothers (20 to 44 y old) and mothers age 45 to 49 relative to the IMR over three decades for 20 African countries. The magnitude of the shift from a live birth-oriented perspective on mortality conditions to a mother-focused view is stark.

During the late 1980s and early 1990s, approximately one-third of surviving mothers age 20 to 44 in almost all countries had experienced the death of at least one infant. For example, in Niger and Malawi, the IMR stood at roughly 100 deaths per 1,000 live births during the early 1990s, which corresponds to roughly 400 mothers having lost an infant per 1,000 reproductive-age mothers. The mIM for mothers age 45 to 49 is far higher. In Benin, Burkina Faso, Liberia, Malawi, Mali, and Niger, having had at least one infant die was a more common experience than having had all of one's children survive infancy. Only in Namibia is the mIM lower than 100 among reproductive-age mothers (90 per 1,000 in 2013). In no country has the mIM fallen below 100 per 1,000 for mothers age 45 to 49, and only in Benin, Kenya, Namibia, and Zimbabwe has it fallen below 200 per 1,000.

Fig. 2 depicts comparable trends in the mU5M and the U5MR. Throughout the 1980s and 1990s, about one-fifth of live births in sub-Saharan Africa ended in death before age 5. In the vast majority of countries, however, the mU5M for mothers age 45 to 49 exceeded 500—more than one-half of mothers. The mU5M was as high as 750 per 1,000 mothers age 45 to 49 in Benin, Burkina Faso, Malawi, Mali, Niger, and Senegal.

U5MRs have dropped precipitously in recent years; mU5M levels, however, remain astonishingly high. As recently as 2010, the mU5M was above 500 per 1,000 mothers age 45 to 49 in Burkina Faso, Liberia, Malawi, Niger, Nigeria, Rwanda, Tanzania, and Uganda. In all countries save five (Benin, Ghana, Kenya, Namibia, Zimbabwe), more than 200 per 1,000 mothers age 20 to 44 had lost a child under age 5.

*Because of our interest in trends, we present only the analyses for countries in which DHS data have been collected since the late 1980s/early 1990s through 2000s. Estimates from all other countries with DHS data available since 2010 are in *SI Appendix*, Fig. S1.

[†]In no country-years have one-half of this age group even had a child; in recent years, fewer than 15% have. Because the populations of 15- to 19-y-old mothers are small and composed of highly selected mothers, we exclude them. As shown in *SI Appendix*, Fig. S2, these estimates are nearly identical to the IMR: young mothers have had only one child, and they did so recently under current mortality conditions. Nonetheless, that more than 50 teenage mothers per 1,000 have had an infant die in multiple countries raises questions about vulnerabilities associated with bereavement at such a young maternal age.

[‡]The projected probabilities are based on older mothers' past mortality experiences; against the backdrop of dramatic mortality, and in some cases fertility, decline, this is problematic. Due to reductions in mortality and fertility, current 20-y-old mothers are unlikely to experience the same level of child loss as older mothers. This concern motivated us to adopt a parsimonious estimation strategy that requires fewer assumptions.

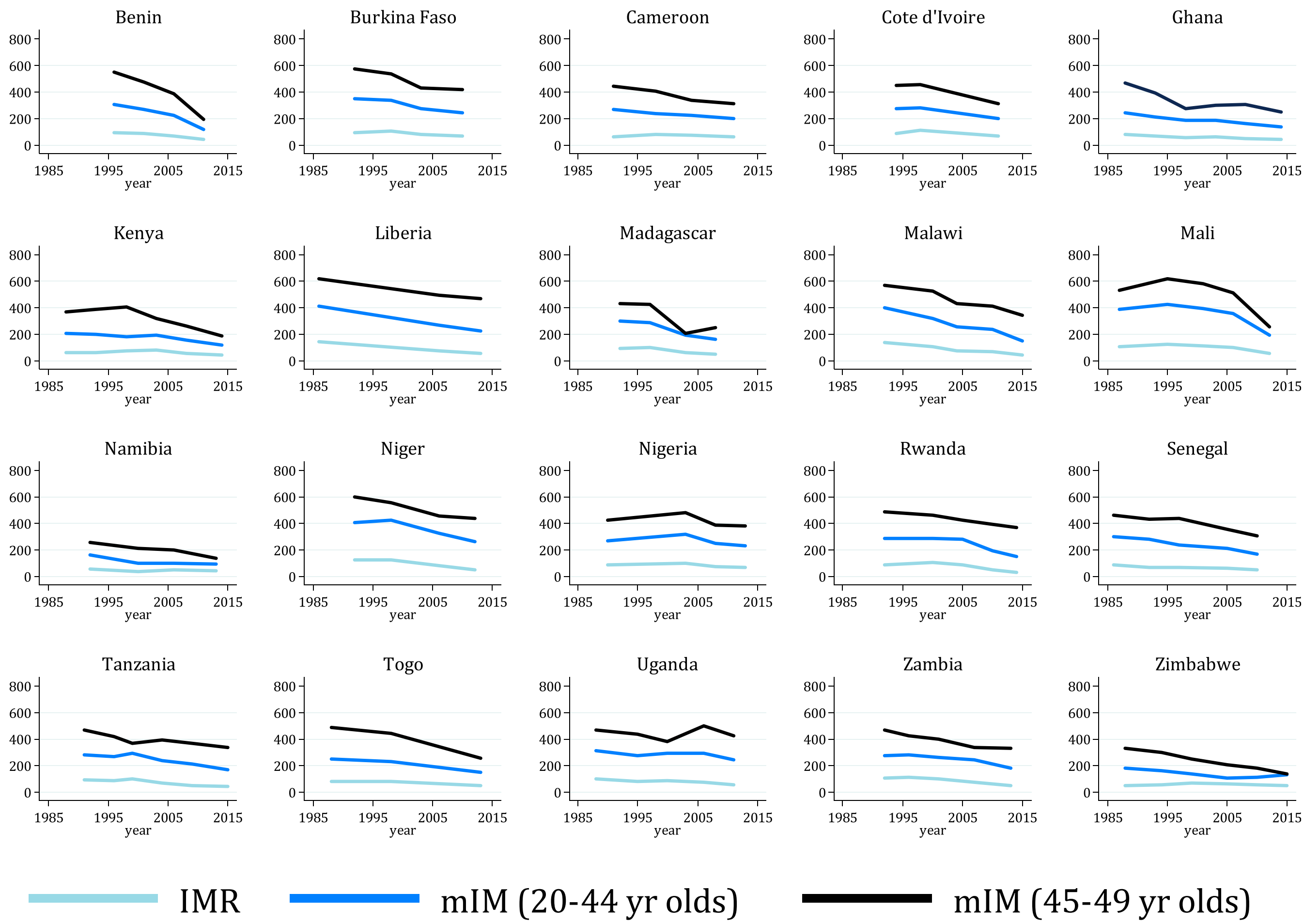

Fig. 1. IMR and mIM for mothers age 20 to 44 and age 45 to 49 in 20 sub-Saharan African countries between circa (c.) 1990s and c. 2010. Expressed per 1,000 live births (IMR) and 1,000 mothers (mIM).

Figs. 1 and 2 also depict the complex correspondence between standard, live birth-oriented mortality measures and these cumulative, mother-centered indicators. Generally speaking, where the reduction in the IMR has been steep, the mIM tends to follow a similar trajectory. Yet, the two measures diverge in some countries. In Uganda, for example, the mIM remained stable even as the IMR fell (Fig. 1). A similar pattern is evident in Niger where, for a select period, stable mortality rates were accompanied by distributional shifts that show even higher prevalence of child death among surviving mothers (Fig. 2). The opposite pattern characterizes Kenya, Rwanda, and Zimbabwe: as the IMR increased, the mIM declined. These divergences could be driven by a complex set of adjacent population changes, including changing causes of death manifesting in shifts in the number of mothers affected; fertility change, which can alter both a mother's exposure and her children's risk of mortality (41); reductions in joint maternal–neonatal deaths; changing patterns of sibling death clustering (3); or a combination.

Because the 20 to 44 age range is wide, it conceals considerable variation in factors like duration of motherhood, number of children, and age profile of children. We calculate the mIM and mU5M for 5-y age groups (*SI Appendix*, Figs. S3 and S4), which allows us to index the experiences of specific age groups. Compared with older mothers, few young mothers have experienced child loss. Even so, the mIM and mU5M often exceed the IMR and U5MR. For instance, as recently as 2010, the mU5M stood at 200 per 1,000 young mothers (age 25 to 29) in eight countries (Burkina Faso, Cameroon, Cote d'Ivoire, Liberia, Mali, Niger, Nigeria, and Uganda) and exceeded 300 per 1,000 mothers in two (Burkina Faso and Niger). Even if the U5MR could be reduced immediately (i.e., aligned with European levels), decades from now large shares of mothers in these populations will have experienced the death of at least one small child. *SI Appendix*, Figs. S3 and S4 show that mortality improvements are dissimilar across distinct age groups of mothers, revealing heterogeneity that our conventional mortality metrics do not capture.

Beyond Infancy and Early Childhood: mOM and mROM. Fig. 3 depicts the prevalence of surviving mothers (age 45 to 49) who ever experienced a child die, regardless of the child's age at death. To offer a sense of scale, we simultaneously plot the corresponding mIM and mU5M. The mOMs show that deaths of older children and adolescents are prevalent and essential to fully capturing the magnitude of child loss in sub-Saharan Africa. As recently as 2010, in 12 countries (Burkina Faso, Cameroon, Cote D'Ivoire, Liberia, Malawi, Niger, Nigeria, Rwanda, Senegal, Tanzania, Uganda, and Zambia), more than one-half of mothers age 45 to 49 had lost at least one child. In some countries, relatively few mothers (10%) who see all of their children survive to age 5 experience an older child die; in other settings (e.g., Kenya, Namibia, and Zimbabwe, which have relatively low U5MRs), however, about 20% of mothers who experience offspring mortality by age 45 to 49 never experienced an under 5 death.

The indicators presented thus far capture the prevalence of mothers who experienced at least one child die; we now adapt

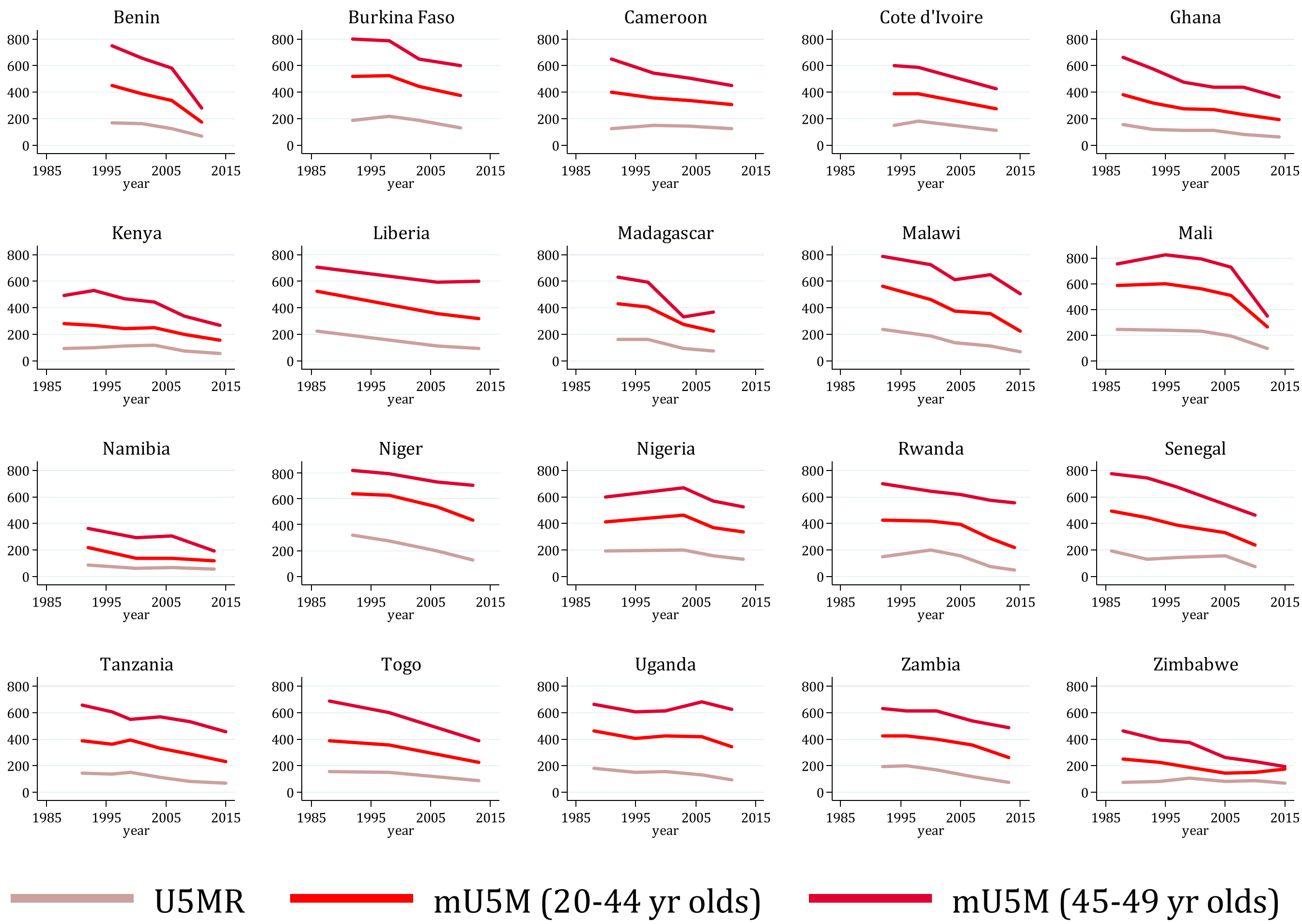

Fig. 2. U5MR and mU5M for mothers age 20 to 44 and age 45 to 49 in 20 sub-Saharan African countries between circa (c.) 1990 and c. 2010. Expressed per 1,000 live births (IMR) and 1,000 mothers (mU5M).

this approach to estimate the prevalence of mROM. Fig. 4 depicts the mROM as a share of the mOM for 45- to 49-y-old mothers. In the 1980s and 1990s, more than 500 mothers per 1,000 in Benin, Burkina Faso, Liberia, Malawi, Mali, Niger, Rwanda, and Senegal had experienced two or more children die. As recently as 2010, the figure stood at around or above 200 per 1,000 mothers in every country but Kenya, Namibia, and Zimbabwe. Viewed alongside the mOM, we see that changes in the prevalence of child loss do not always track neatly with shifts in the prevalence of mothers experiencing recurrent losses.

Calculating Maternal Cumulative Prevalence Indicators for Additional Populations. Our analyses focused on a subsample of 20 sub-Saharan African countries in which the DHS program has collected data from the early 1990s through 2010, allowing for an analysis of change over time. *SI Appendix*, Fig. S1 includes estimates for 16 additional African countries that fielded a DHS survey in the past decade. Population health researchers can easily calculate the mIM, mU5M, and mOM annually and publish them alongside standard measures like the IMR and U5MR to offer a new, distinct view of mortality conditions. Because they draw on routinely collected data, their addition adds little burden to measurement systems in low-income countries.

Where nationally representative data on mothers' age and child loss are unavailable, researchers can estimate mother-centered mortality measures indirectly by adapting the equation used for estimating the lifetime risk of maternal mortality (42).[§] Supplementary analyses demonstrate that the indirect method estimates the mU5M within ∼10% of the mU5M values shown in *SI Appendix*, Fig. S1, although this approach generates estimates that are less accurate for the mIM. Nonetheless, this approach generates rough estimates in settings where the minimally requisite reproductive histories are unavailable.

Conversely, where microdata are available, these measures can be calculated at smaller aggregates, allowing researchers to investigate the more immediate subnational or community contexts within which mothers live. To illustrate, *SI Appendix*, Fig. S5 displays the mOM for each of the 20 focal countries by subnational region, revealing stark subnational differences in the prevalence of mothers who have experienced a child die. Mother-centered indicators further illuminate inequality in the mortality burden across social groups: for example, by wealth quintile (*SI Appendix*, Fig. S6). As depicted in *SI Appendix*, Fig. S6, mortality change has benefited mothers in certain social strata more than others: in many countries, only mothers in the wealthiest households are meaningfully insulated from child loss.

Discussion

Focusing on sub-Saharan Africa, we show that, even in the wake of notable improvements in mortality conditions, the death of a

§The equations are $mIM = 1 - ((1 - IMR)^{TFR})$ and $mU5M = 1 - ((1 - U5MR)^{TFR})$.

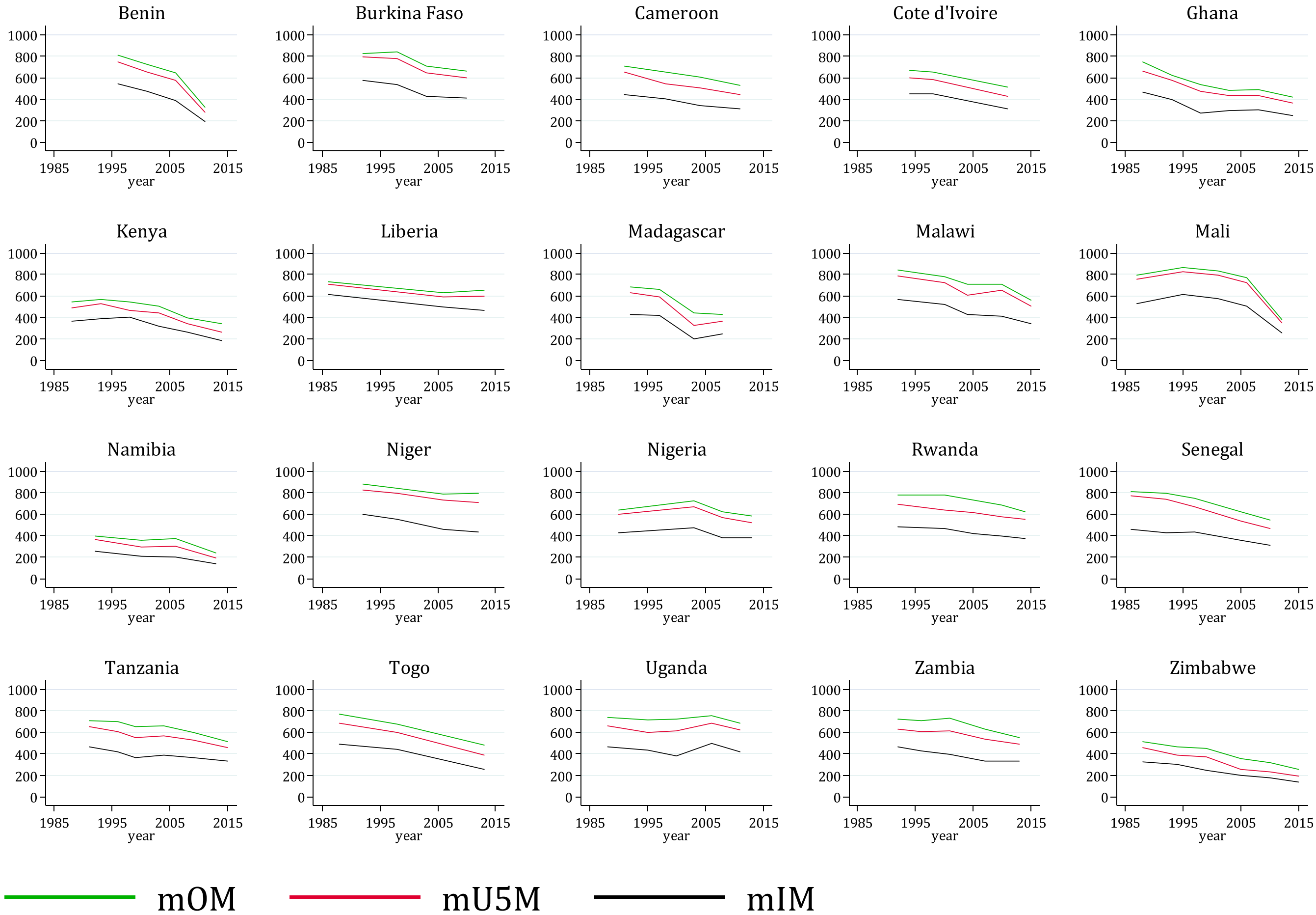

Fig. 3. mIM, mU5M, and mOM among mothers age 45 to 49 in 20 sub-Saharan African countries between circa (c.) 1990 and c. 2010. Expressed per 1,000 mothers.

child remains an extraordinarily common experience: between one-quarter and one-half of mothers in contemporary African populations have experienced the death of at least one child. These findings have implications for public health and population theory.

Given the mOM in contemporary Africa, the limited empirical work on its consequences is problematic. A rich literature details the far-reaching and long-lasting consequences of child death for parents in high-income countries (6), yet research on African settings primarily concerns itself with whether child mortality affects women's subsequent fertility—with the exception of a few studies (13–17), the subsequent disadvantages for African mothers remain understudied. Bereavement should be prioritized as a scholarly issue on a global scale, and it should be engaged in policy circles as a true threat to public health in sub-Saharan Africa.

By summarizing a mortality regime from the perspective of mothers, these indicators can inform theories of population change, especially to the extent that they approximate the mortality burden that women perceive. Mortality perceptions are notoriously complex; they are strongly informed by the experiences of similar others (32) and tend to be overassessed in comparison with true mortality levels due to cognitive biases (43). For example, cognitive research on negativity bias suggests that child survival in one's network is a forgettable, null event, whereas a child's death registers as memorable and influential. Cognitive research on the primacy effect suggests that time is also a factor: women's mortality perceptions may be anchored in their own childhood conditions, giving more weight to earlier experiences and less weight to contemporary patterns and events. Insights from this study suggest yet another possible explanation: elevated mortality perceptions among women could be driven by their treatment of the denominator when assessing risk. Psychologists frequently point to "denominator neglect" in puzzles of risk assessment (44), but we posit that cognitive egocentrism may mean that women perceive child death as a fundamentally maternal phenomenon—placing themselves and other mothers in the denominator. From this perspective, it follows that mothers' mortality perceptions are calibrated to the prevalence of mothers who have experienced children die rather than the number of live births that have ended in death.

To explore this idea, we turned to a population-based study in Malawi. Tsogolo la Thanzi (45) measured young women's perceptions of infant mortality using an interactive elicitation method (46) in which interviewers gave respondents 10 beans and asked the women to shift from one plate to another the number of beans representing the likelihood that a child born today would die within the year. In 2009, the mean response was two beans, which we interpret as women perceiving that, on average, 20% of infants would die—a major overassessment because at this time, the IMR stood at 58.4 deaths per 1,000 births (47). The mIM for mothers age 20 to 44 in Malawi, however, was 237 in 2010. This close correspondence between perceived survival probability and the mIM suggests that, when contemplating the risks that infants face, women may be thinking of the mothers around them, not about live births.

By quantifying the burden of child death on African mothers, mother-centered indicators of mortality add a dimension to contemporary and historical portraits of mortality decline. These measures quantify the extent to which a legacy of high mortality lives on in surviving mothers: even though mortality rates have

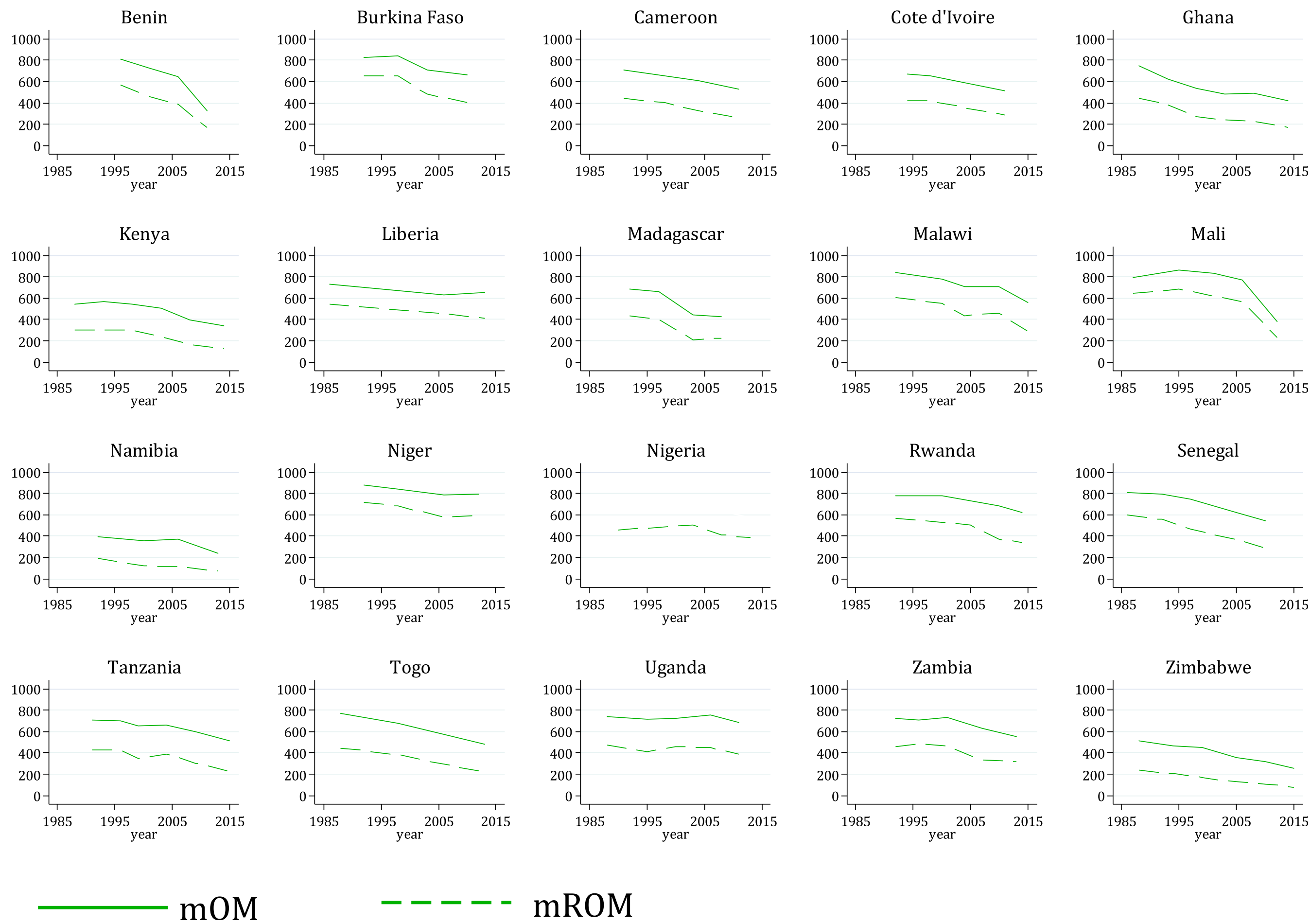

Fig. 4. mOM and mROM among mothers age 45 to 49 in 20 sub-Saharan African countries between circa (c.) 1990 and c. 2010. Expressed per 1,000 mothers.

declined, the number of African mothers who have lost a child remains very high. If these measures truly approximate the mortality perceptions held by surviving adults in a population, they may possess more predictive power vis-à-vis fertility behaviors than the IMR. These measures could be leveraged to shed light on fertility decline and the unique patterns of family change that characterize sub-Saharan Africa (48–50). The simultaneous deployment of these maternal cumulative prevalence measures alongside standard annualized measures will be valuable descriptively for scholars of global health and analytically relevant for research on inequality, mortality trends, child bereavement, and population dynamics.

Data Availability. All data used in this study are publicly available. DHS data are available at https://dhsprogram.com/ and https://www.statcompiler.com/en/. Tsogolo la Thanzi data are available at https://www.icpsr.umich.edu/icpsrweb/DSDR/studies/36863. Replication files are posted at Harvard Dataverse, https://doi.org/10.7910/DVN/3FGPTM (40).

ACKNOWLEDGMENTS. The paper benefited from audience comments at the 2019 Annual Meeting of the Population Association of America, the 2019 American Sociological Association's Sociology of Development Section conference, UCLA's California Center for Population Research seminar, University of California Irvine's Population, Society, and Inequality seminar, and the Max Planck Institute for Demographic Research lecture series. We thank Tom Pullum, Stephane Helleringer, and Ashton Verdery for their comments on an early version, Alli Coritz and Rachel Kosic for research assistance, and the PNAS editors and reviewers for valuable feedback throughout the review process. The DHS is funded by USAID.

1. L. Hug, D. Dharrow, K. Zhong, D. You, "Levels and trends in child mortality: Report 2018 (English)" (Rep. 129971, World Bank Group, Washington, D.C., 2018).
2. D. You *et al.*; United Nations Inter-agency Group for Child Mortality Estimation (UN IGME), Global, regional, and national levels and trends in under-5 mortality between 1990 and 2015, with scenario-based projections to 2030: A systematic analysis by the UN inter-agency group for child mortality estimation. *Lancet* **386**, 2275–2286 (2015).
3. M. Das Gupta, Death clustering, mothers' education and the determinants of child mortality in rural Punjab, India. *Popul. Stud.* **44**, 489–505 (1990).
4. D. Umberson *et al.*, Death of family members as an overlooked source of racial disadvantage in the United States. *Proc. Natl. Acad. Sci. U.S.A.* **114**, 915–920 (2017).
5. J. Fletcher, M. Vidal-Fernandez, B. Wolfe, Dynamic and heterogeneous effects of sibling death on children's outcomes. *Proc. Natl. Acad. Sci. U.S.A.* **115**, 115–120 (2018).
6. M. Stroebe, W. Stroebe, G. Abakoumkin, The broken heart: Suicidal ideation in bereavement. *Am. J. Psychiatry* **162**, 2178–2180 (2005).
7. C. H. Rogers, F. J. Floyd, M. M. Seltzer, J. Greenberg, J. Hong, Long-term effects of the death of a child on parents' adjustment in midlife. *J. Fam. Psychol.* **22**, 203–211 (2008).
8. J. Song, F. J. Floyd, M. M. Seltzer, J. S. Greenberg, J. Hong, Long-term effects of child death on parents' health related quality of life: A dyadic analysis. *Fam. Relat.* **59**, 269–282 (2010).
9. J. Li, T. M. Laursen, D. H. Precht, J. Olsen, P. B. Mortensen, Hospitalization for mental illness among parents after the death of a child. *N. Engl. J. Med.* **352**, 1190–1196 (2005).
10. I. Levav *et al.*, Cancer incidence and survival following bereavement. *Am. J. Public Health* **90**, 1601–1607 (2000).
11. J. Li, D. H. Precht, P. B. Mortensen, J. Olsen, Mortality in parents after death of a child in Denmark: A nationwide follow-up study. *Lancet* **361**, 363–367 (2003).
12. J. Johnson-Hanks, *Uncertain Honor: Modern Motherhood in an African Crisis* (University of Chicago Press, 2006).
13. S. E. Castle, The (re) negotiation of illness diagnoses and responsibility for child death in rural Mali. *Med. Anthropol. Q.* **8**, 314–335 (1994).
14. J. Einarsdóttir, *Tired of Weeping: Mother Love, Child Death, and Poverty in Guinea-Bissau* (University of Wisconsin Press, 2005).
15. R. A. Haws *et al.*, "These are not good things for other people to know": How rural Tanzanian women's experiences of pregnancy loss and early neonatal death may impact survey data quality. *Soc. Sci. Med.* **71**, 1764–1772 (2010).

16. K. A. Dettwyler, *Dancing Skeletons: Life and Death in West Africa* (Waveland Press, 2013).
17. A. Weitzman, E. Smith-Greenaway, "The marital implications of bereavement: Child death and intimate partner violence in West and Central Africa" in *Session 59*. *Causes of Neonatal, Infant, and Child Mortality* (Population Association of America, 2019).
18. J. Cleland, The effects of improved survival on fertility: A reassessment. *Popul. Dev. Rev.* **27**, 60–92 (2001).
19. K. O. Mason, Explaining fertility transitions. *Demography* **34**, 443–454 (1997).
20. S. H. Preston, *The Effects of Infant and Child Mortality on Fertility* (Academic Press, New York, NY, 1978).
21. D. S. Reher, The demographic transition revisited as a global process. *Popul. Space Place* **10**, 19–41 (2004).
22. R. A. Easterlin, E. M. Crimmins, *The Fertility Revolution: A Supply-Demand Analysis* (University of Chicago Press, 1985).
23. F. W. Notestein, *Economic Problems of Population Change* (Oxford University Press, London, UK, 1953).
24. R. Lee, The demographic transition: Three centuries of fundamental change. *J. Econ. Perspect.* **17**, 167–190 (2003).
25. J. Nobles, E. Frankenberg, D. Thomas, The effects of mortality on fertility: Population dynamics after a natural disaster. *Demography* **52**, 15–38 (2015).
26. P. Heuveline, B. Poch, The phoenix population: Demographic crisis and rebound in Cambodia. *Demography* **44**, 405–426 (2007).
27. T. LeGrand *et al*., Reassessing the insurance effect: A qualitative analysis of fertility behavior in Senegal and Zimbabwe. *Popul. Dev. Rev.* **29**, 375–403 (2003).
28. J. Sandberg, Infant mortality, social networks, and subsequent fertility. *Am. Sociol. Rev.* **71**, 288–309 (2006).
29. M. Montgomery, J. B. Casterline, F. Heiland, *Social Networks and the Diffusion of Fertility Control* (Population Council New York, 1998).
30. D. Shapiro, M. Tenikue, Women's education, infant and child mortality, and fertility decline in urban and rural sub-Saharan Africa. *Demogr. Res.* **37**, 669–708 (2017).
31. V. Atella, F. C. Rosati, Uncertainty about children's survival and fertility: A test using indian microdata. *J. Popul. Econ.* **13**, 263–278 (2000).
32. J. Sandberg, S. Rytina, V. Delaunay, A. S. Marra, Social learning about levels of perinatal and infant mortality in Niakhar, Senegal. *Soc. Networks* **34**, 264–274 (2012).
33. A. Palloni, H. Rafalimanana, The effects of infant mortality on fertility revisited: New evidence from Latin America. *Demography* **36**, 41–58 (1999).
34. A. Coale, "The demographic transition reconsidered" in *Proceedings of the International Population Conference* (International Union for the Scientific Study of Population, Liège, 1973), vol. 1, pp. 53–72.
35. G. C. Patton *et al*., Global patterns of mortality in young people: A systematic analysis of population health data. *Lancet* **374**, 881–892 (2009).
36. A. Deaton, Height, health, and development. *Proc. Natl. Acad. Sci. U.S.A.* **104**, 13232–13237 (2007).
37. M. Mahy, *Childhood Mortality in the Developing World: A Review of Evidence from the Demographic and Health Surveys* (MEASURE DHS+, ORC Macro, 2003), vol. 4.
38. A. Koski, S. Clark, A. Nandi, Has child marriage declined in sub-Saharan Africa? An analysis of trends in 31 countries. *Popul. Dev. Rev.* **43**, 7–29 (2017).
39. M. C. Hogan *et al*., Maternal mortality for 181 countries, 1980-2008: A systematic analysis of progress towards millennium development goal 5. *Lancet* **375**, 1609–1623 (2010).
40. E. Smith-Greenaway, Replication Data for "Maternal Cumulative Prevalence Measures of Child Mortality Show Heavy Burden in Sub-Saharan Africa". Proceedings of the National Academy of Sciences (2020). Harvard Dataverse, V1. https://doi.org/10.7910/DVN/3FGPTM. Deposited 17 January 2020.
41. J. Menken, J. F. Phillips, Population change in a rural area of Bangladesh, 1967-87. *Ann. Am. Acad. Pol. Soc. Sci.* **510**, 87–101 (1990).
42. J. Wilmoth, The lifetime risk of maternal mortality: Concept and measurement. *Bull. World Health Organ.* **87**, 256–262 (2009).
43. M. R. Montgomery, Perceiving mortality decline. *Popul. Dev. Rev.* **26**, 795–819 (2000).
44. V. F. Reyna, C. J. Brainerd, Numeracy, ratio bias, and denominator neglect in judgments of risk and probability. *Learn. Individ. Differ.* **18**, 89–107 (2008).
45. S. Yeatman, A. Chilungo, S. Lungu, H. Namadingo, J. Trinitapoli, Tsogolo la Thanzi: A longitudinal study of young adults living in Malawi's HIV epidemic. *Stud. Fam. Plann.* **50**, 71–84 (2019).
46. A. Delavande, H.-P. Kohler, Subjective expectations in the context of HIV/AIDS in Malawi. *Demogr. Res.* **20**, 817–874 (2009).
47. D. Malawi, *Malawi Demographic and Health Survey* (NSO and ICF Macro, Zomba, Malawi, 2010).
48. J. Bongaarts, Africa's unique fertility transition. *Popul. Dev. Rev.* **43**, 39–58 (2017).
49. A. Goujon, W. Lutz, S. Kc, Education stalls and subsequent stalls in African fertility: A descriptive overview. *Demogr. Res.* **33**, 1281–1296 (2015).
50. E. Kebede, A. Goujon, W. Lutz, Stalls in Africa's fertility decline partly result from disruptions in female education. *Proc. Natl. Acad. Sci. U.S.A.* **116**, 2891–2896 (2019).