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Education and Fertility Dynamics in Low-and Middle-Income Countries: A Comparative Study

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Abstract

Many studies report an inverse relationship between education and female fertility outcomes, particularly total fertility rates and the timing of childbearing. Although this association has weakened in recent years across some settings, it remains especially relevant for understanding both past and future fertility patterns in low- and middle-income countries. Persistent data limitations make it difficult to document the historical evolution of the relationship between education and fertility rates in these contexts. More specifically, in sub-Saharan Africa, research on education and fertility decline remains scarce and has focused mainly on women. Available evidence typically shows that the negative association becomes most apparent from the secondary education level onwards.

This dissertation provides a nuanced understanding of several key areas of research. First, it presents education-specific fertility rates across selected countries in Africa and Latin America. Second, it examines the role of literacy skills in fertility outcomes among women in sub-Saharan Africa. Third, it investigates fertility in relation to education while incorporating male fertility and spousal dynamics, thereby addressing gender asymmetries in fertility research within the region.

Adopting a thesis-by-publication format, this dissertation combines four studies that apply a range of modelling techniques to fertility data. The findings across the papers show that education is consistently associated with lower fertility among women, although the strength and timing of this association vary across contexts and over time. Reconstructed education- and age-specific fertility rates suggest persistent educational differentials in sub-Saharan Africa, while in other regions these gaps have narrowed. Moreover, fertility outcomes differ by literacy skills within educational levels, with stronger associations for completed fertility than for the timing of first births. Changing partnership dynamics are also associated with education, as spousal age gaps have declined through varied mechanisms across countries. Finally, male fertility appears more closely associated with relationship status and birth cohort than with education alone. Taken together, the studies in this thesis suggest that the association between education and fertility outcomes operates through multiple pathways, including women's fertility behaviour, literacy, partnership dynamics, and men's fertility level.

Kurzfassung

Viele Studien berichten über einen umgekehrten Zusammenhang zwischen Bildung und der weiblichen Fertilität, insbesondere hinsichtlich der Gesamtfruchtbarkeitsrate und des Zeitpunkts der Geburt. Obwohl dieser Zusammenhang in den letzten Jahren in einigen Regionen schwächer geworden ist, bleibt er für das Verständnis sowohl vergangener als auch zukünftiger Fertilitätsmuster in Ländern mit niedrigem und mittlerem Einkommen besonders relevant. Anhaltende Datenbeschränkungen erschweren es jedoch, die historische Entwicklung des Zusammenhangs zwischen Bildung und Fertilität in diesen Kontexten zu dokumentieren. Insbesondere in Subsahara-Afrika gibt es nach wie vor nur wenige Forschungsarbeiten zum Thema Bildung und Rückgang der Fertilität, die sich zudem hauptsächlich auf Frauen konzentrieren. Die verfügbaren Erkenntnisse zeigen in der Regel, dass der negative Zusammenhang ab der Sekundarstufe am deutlichsten wird.

Diese Dissertation vermittelt ein differenziertes Verständnis mehrerer wichtiger Forschungsbereiche. Erstens werden die bildungsspezifischen Fertilitätsraten in ausgewählten Ländern Afrikas und Lateinamerikas dargestellt. Zweitens wird die Rolle der Lese- und Schreibkompetenz für die Fertilitätsergebnisse von Frauen in Subsahara-Afrika untersucht. Drittens wird die Fertilität in Bezug auf Bildung unter Einbeziehung der männlichen Fertilität und der Partnerschaftsdynamiken untersucht, wodurch geschlechtsspezifische Asymmetrien in der Fertilitätsforschung innerhalb der Region thematisiert werden.

Diese Dissertation, die im Format einer Thesis-by-Publication verfasst wurde, vereint vier Studien, in denen verschiedene Modellierungstechniken auf Fertilitätsdaten angewendet werden. Die Ergebnisse aller Arbeiten zeigen, dass Bildung durchweg mit einer geringeren Fertilität bei Frauen verbunden ist, obwohl die Stärke und der Zeitpunkt dieses Zusammenhangs je nach Kontext und im Zeitverlauf variieren. Rekonstruierte bildungs- und altersspezifische Fertilitätsraten deuten auf anhaltende Bildungsunterschiede in Subsahara-Afrika hin, während sich diese Unterschiede in anderen Regionen verringert haben. Darüber hinaus unterscheiden sich die Fertilitätsergebnisse je nach Lese- und Schreibfähigkeiten innerhalb der Bildungsstufen, wobei der Zusammenhang für die abgeschlossene Fertilität stärker ist als für den Zeitpunkt der ersten Geburten. Auch die veränderten Partnerschaftsdynamiken hängen mit der Bildung zusammen, da die Altersunterschiede zwischen Ehepartnern durch unterschiedliche Mechanismen in den einzelnen Ländern zurückgegangen sind. Schließlich scheint die männliche Fertilität enger mit dem Beziehungsstatus und der Geburtskohorte zusammenzuhängen als mit der Bildung allein. Insgesamt legen die Studien in dieser Arbeit nahe, dass der Zusammenhang zwischen Bildung und Fertilitätsergebnissen über mehrere Wege wirkt, darunter das Fertilitätsverhalten von Frauen, Alphabetisierung, Partnerschaftsdynamik und die männliche Fertilität. Diese Erkenntnisse sind wertvoll für Forscher und politische Entscheidungsträger, die sich für die Verbesserung der Bildung und die Entwicklung wirksamer politischer Maßnahmen einsetzen.

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Contents

1. Introduction

1.1. Research Motivation

Demographic transition theory, introduced by Notestein (1945), remains a foundational model for explaining shifts from high to low fertility and mortality. However, its application often assumes universal trajectories, overlooking regional variations (Bongaarts, 2017; Bongaarts & Casterline, 2013; Teller & Hailemariam, 2011). Over the decades, demographers have emphasised that education—particularly female education—is widely associated with differences in fertility patterns during this transition (Lutz et al., 2018; Sharma et al., 2021; Van Bavel et al., 2018). Central to the demographic transition lies a societal shift from traditional to modern norms and practices, during which a series of changes in reproductive and health outcomes unfold (Coale, 1989). Although scholars have widely studied the relationship between education and fertility, much of the literature conceptualises the relationship as one where each additional level of education uniformly delays childbearing and reduces fertility (for example, Duflo et al., 2010; Ferré, 2009; Glick et al., 2015; Osili & Long, 2008). Rather than proposing a unified theoretical model, this dissertation empirically contributes to expanding existing frameworks by highlighting understudied pathways linking education to fertility outcomes. Building on the critiques of demographic transition theory and its generalisability to sub-Saharan Africa (Canning et al., 2015; Teller & Hailemariam, 2011)—where fertility remains high despite educational expansions (Bongaarts, 2017)—this dissertation expands the framework by incorporating male fertility, literacy, and spousal age gaps, factors often excluded from standard models.

Despite a constant interest in the education-fertility relationship, empirical evidence from low- and middle-income countries remains limited, particularly regarding the dynamics of education-specific fertility rates over time (Van Zanden, 2011; Yildiz et al., 2023). The Wittgenstein Centre for Demography and Global Human Capital (WIC) produces global projections of education-specific population sizes and projections of education-specific indicators, such as fertility rates (Lutz et al., 2018). However, the WIC does not provide historical fertility rates by level of education. This gap is consequential, given the established link between female education and the fertility transition. In sub-Saharan Africa, Structural Adjustment Programmes (SAPs) coincided with disruptions in female education, which were potentially related to observed stalls in fertility decline (Goujon et al., 2015; Kebede et al., 2019). At the same time, the region exhibits broader fertility differentials by education level than in other parts of the world (Bongaarts, 2003). This relationship makes the region a key area of focus for understanding the complex association between education and fertility (for example, Grant, 2015; Nishimura et al., 2009; Smith-Greenaway, 2015; Sserwanja et al., 2023). Therefore, the first of four studies in this dissertation reconstructs education-specific fertility rates for 1970–2020 across low- and middle-income countries. This dataset facilitates comparisons of country- and education-specific fertility rates, providing empirical evidence on the timing of the fertility transition. By addressing the gap in education-specific fertility data, this study improves understanding of how education is related to fertility decline in low- and middle-income countries.

Higher education—particularly tertiary education—has been associated with delays in first births among women in low-fertility settings (Nathan & Pardo, 2019; Neels et al., 2017; Ní Bhrolcháin & Beaujouan, 2012; Sobotka, 2017). However, some studies have found that education alone does not always strongly correlate with first-birth delays (Rodgers et al., 2008; Tropf & Mandemakers, 2017). These findings suggest that other factors, such as economic conditions, social norms, and access to healthcare, may also be related to fertility decisions. In settings that have yet to complete the fertility transition, evidence is mixed: some studies identify a relationship between education and delayed first birth (Glick et al., 2015; Mugarura et al., 2016), whereas others do not observe a relationship between universal primary education policies aimed at educational expansion and increased age at first birth (Grant, 2015). Additional analyses indicate that delays are most strongly associated with secondary education onwards (Frye & Lopus, 2025; Obeng Gyimah, 2003). Overall, education is fundamental, but it is not the sole driver of fertility change, particularly in regions where gender norms or cultural practices remain salient in women's reproductive choices. Literacy disparities may further complicate the relationship between education and fertility. For instance, in West and Central Africa, many women with five years of primary education are unable to read (Smith-Greenaway, 2015). Between 2000 and 2010, net primary enrolment grew in sub-Saharan Africa by approximately 14%, whereas literacy rates increased by about 4% (Ritchie et al., 2023; Roser & Ortiz-Ospina, 2016). These figures suggest that literacy, in addition to years spent in school, may be associated with fertility outcomes, including age at first birth and completed fertility (Bongaarts, 2010; Kirk & Pillet, 1998). Accordingly, the second study of the dissertation investigates the role of literacy, through education, in age at first birth and completed fertility among women in sub-Saharan Africa.

Large spousal age gaps, particularly above ten years, are associated with lower contraceptive use, reduced female autonomy, and greater gender power imbalances (Kyei et al., 2025; Shapiro & Gebreselassie, 2014). Moreover, sub-Saharan Africa reports one of the widest spousal age gaps in the world (Ausubel et al., 2022; Barbieri et al., 2005; Feng & Ren, 2022). Education is a key factor in narrowing these gaps, as men and women with secondary or higher education consistently report smaller mean spousal age differences (Bongaarts, 2017; Kyei & Bawah, 2024). Ghana and Kenya offer well-suited case studies: both adopted Universal Primary Education (UPE) programmes around the same time, differ in ideologies and in the prevalence of polygamy, and exhibit comparable fertility levels (Bado et al., 2022; Kramer, 2020; Nishimura et al., 2009; Tabutin et al., 2020). Therefore, the third study of this dissertation examines gender differences in age at union formation to better understand how education interacts with partnership dynamics. It examines how male, female, and couples' (partners matched at the household level) education relates to spousal age gaps in Ghana and Kenya. This study also assesses how changes in the share of couples with high age gaps (≥ ten years) contribute to the change in the mean spousal age gap.

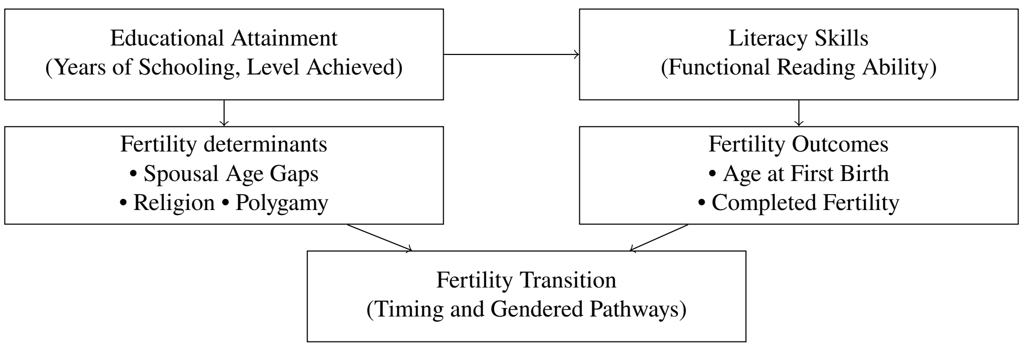
In contrast to the extensive literature on female education and fertility decline, few studies have focused on male fertility, specifically men's education and fertility patterns (Duze & Mohammed, 2006; Menashe-Oren & Sánchez-Páez, 2023; Schoumaker, 2019). This omission is particularly important in sub-Saharan Africa, where fertility remains high despite educational expansion (Bongaarts, 2017). Fertility outcomes depend on both partners, and men's education and reproductive behaviours are associated with patterns of union formation, spousal age gaps, and family size (Schoumaker, 2013a). The limited evidence reveals notable disparities between male and female fertility; male fertility rates are likely to be higher, and men typically become parents at later ages compared to women (Schoumaker, 2017b). Moreover, the sparse studies that focus on education show that men with some education tend to have fewer children—a relationship also observed among women in the region (Menashe-Oren & Sánchez-Páez, 2023). The fourth study exclusively focuses on male fertility levels. Focusing on the interplay between male and female education, the study sheds light on the underexplored dimensions of fertility transitions in sub-Saharan Africa, offering a more comprehensive understanding of the factors driving fertility change. In doing so, the dissertation also highlights the role of education, among other determinants, in understanding male fertility patterns.

Conceptual and theoretical framework

The relationship between education and fertility decline is central to demographic transition theory, particularly the fertility transition (Caldwell, 1980; Notestein, 1945). Historically, rising educational attainment, particularly among women, has been associated with fertility reductions through mechanisms such as delayed marriage, increased contraceptive use, and improved child survival (Axinn & Barber, 2001; Bongaarts, 2003; Lutz & Samir, 2011; Lutz et al., 2018). However, this relationship is complex in low- and middle-income countries, particularly in sub-Saharan Africa, where fertility declines have often been slow, partial, or stalled despite educational expansion (Bado et al., 2022; Goujon et al., 2015; Kebede et al., 2019; Schoumaker & Sánchez-Páez, 2024).

This dissertation builds on existing theory by adopting a multidimensional and context-specific framework. The framework proposed for this thesis centres on the fertility transition rather than the demographic transition as a whole. Instead of viewing education as one-dimensional, this framework, presented in Figure 1.1, highlights how education, alongside other determinants, such as literacy, interacts with cultural settings to shape variations in fertility outcomes.

Figure 1.1: Conceptual framework: Selected pathways linking education to fertility outcomes



The framework positions education as a central factor associated with fertility behaviour whose demographic impact is mediated by:

1. The acquisition of literacy skills, not always derived through formal schooling;
2. Gendered social and marriage norms, which may be linked to spousal age gaps;

3. Religious affiliation, polygamy, and birth cohorts that modulate the translation of education into behavioural change.

Altogether, the conceptual framework proposed in this dissertation offers a more context-specific understanding of how education relates to fertility outcomes in low- and middle-income countries. Each of the four papers in this thesis empirically engages a different component of this framework. Paper 1 reconstructs education-specific fertility rates, Paper 2 investigates the role of literacy in fertility outcomes, Paper 3 explores spousal age gaps, and Paper 4 integrates male fertility alongside other determinants, such as relationship status and religion.

This dissertation contributes to ongoing theoretical debates by empirically integrating several understudied dimensions, such as literacy, male fertility, and spousal age gaps, into demographic analysis. Building on existing theory, it challenges simplified assumptions about how education is associated with fertility across various contexts.

1.2. Research Gaps

Although the association between education and fertility decline is well established, gaps remain in understanding how this relationship has evolved in low- and middle-income countries (LMICs). A significant obstacle in addressing this issue lies in the limited availability and reliability of registry data from LMICs. The main challenge lies in the limitations of the available data sources. The Demographic and Health Surveys (DHS), for instance, remains an invaluable source for fertility research in LMICs but faces issues of data quality, such as recall bias, omission of events, and age heaping, where respondents tend to round their ages to the nearest multiple of five, potentially leading to biased results (Al Zalak & Goujon, 2017; Rutstein & Rojas, 2006; Schoumaker, 2011, 2014). The UN World Population Prospects (UN WPP) provides regularly updated, internationally recognised fertility estimates that rely on probabilistic modelling and synthesise diverse sources rather than providing education-specific rates (United Nations Population Division, 2023; Wittgenstein Centre Human Capital Data Explorer, 2023). The WIC produces modelled estimates of population sizes and demographic indicators disaggregated by education, but education-specific fertility rate estimates are only available from 2015 onwards and do not cover historical periods (Wittgenstein Centre Human Capital Data Explorer, 2023). These limitations highlight the absence of consistent, long-term, education-specific fertility rates. Traditional estimation approaches are poorly suited to bridging these gaps, as they often assume complete and uniformly defined datasets. Bayesian methods are suitable for integrating heterogeneous demographic data because they explicitly account for varying precision and missing information (Alkema et al., 2008; Bijak & Bryant, 2016). This approach is beneficial for research on LMICs, where data inconsistencies are prevalent. Such an approach could help generate comparable historical education-specific fertility rates, enhancing understanding of the relationship between education and fertility in these regions.

Another area of fertility and education research in sub-Saharan Africa with limited research is the relationship between education, literacy skills, completed fertility, and age at first birth for women. Educational expansions, such as Free Primary Education (FPE) and Universal Primary Education (UPE) initiatives, have been widely implemented in sub-Saharan Africa as part of broader policy efforts aimed at reducing fertility rates, which are often seen as too high in the context of population growth (Caldwell & Caldwell, 1990). However, these expansions, including variations in UPE and FPE, have corresponded to minimal shifts in fertility patterns, especially at the primary level (Grant, 2015; Mugarura et al., 2016; Vavrus & Larsen, 2003). Simultaneously, evidence supports that disruptions in educational expansion are associated with many observed stalls and even reversals in fertility decline across sub-Saharan Africa (DeRose & Kravdal, 2007; Goujon et al., 2015; Kebede et al., 2019; Schoumaker & Sánchez-Páez, 2024). Another concern is the disparity in literacy skills, especially among women with only primary education in the region (Smith-Greenaway, 2015). The inequality in literacy skill acquisition among women with primary education raises questions about whether literacy skills alone, as a core outcome of education, are related to fertility decline. While accounting for the education level of mothers, literacy skills in other low- and middle-income countries emerged as vital in increasing child survival, which led to a reduction in fertility levels (LeVine et al., 2011). As LeVine et al. (2011) showed, women with some literacy skills were able to understand health messages and thus implement them, allowing them to reduce child mortality. Within sub-Saharan Africa, women with secondary or higher education consistently have lower fertility, but this pattern is less straightforward among women with only primary education (Durowaa-Boateng et al., 2023; Schoumaker & Sánchez-Páez, 2024). Differences in skill acquisition at the primary level—particularly in literacy, where women with the same years of schooling can range from illiterate to fully literate—may help explain why fertility declines are more pronounced after secondary education than after primary. Variations in literacy skills at the primary level stem from unequal access to quality schooling and disparities in education quality arising from the dual (private versus public) system (Tooley & Dixon, 2005, 2006). These relationships emphasise the need for further research to determine whether the education level or the skills acquired during education matter for fertility outcomes.

The gendered nature of fertility behaviour in sub-Saharan Africa also presents a significant research challenge. In countries where the fertility transition (from high to low) has progressed, the age gap between men and women at the time of union formation and childbearing tends to decrease (Dudel & Klüsener, 2021). However, the spousal age gap in sub-Saharan Africa remains relatively wide, one of the highest among world regions (Ausubel et al., 2022). In earlier studies, the median age at first marriage for women in sub-Saharan Africa was approximately 20 years, with differences across countries, educational levels, and religion (Harwood-Lejeune, 2001; Hertrich, 2017). Males form unions in sub-Saharan Africa substantially later than females (Boserup, 1985; Marston et al., 2009) and often have significantly higher fertility rates than women, as evidenced by countries such as Mali and Niger, where the male total fertility rates (TFR) are approximately 10.4 and 12, respectively, which is double the fertility rate of women (Schoumaker, 2019). Despite a growing body of research on female education and fertility in sub-Saharan Africa, there remains a paucity of studies examining male fertility behaviour, particularly regarding education level (Menashe-Oren & Sánchez-Páez, 2023; Schoumaker, 2017a). Previous studies on female education and age at marriage have shown that education increases the age at marriage, and spousal age gaps are lower for women with higher levels of education (Amoo, 2017; Kyei & Bawah, 2024). However, no study has yet directly examined how male, female, and couples' (dyadic) education levels are associated with the age gap in unions in sub-Saharan Africa. This research gap presents an opportunity to explore how educational attainment and the gendered nature of education are associated with fertility behaviours in this region.

Research on migrant men in sub-Saharan Africa has shown that educated men tend to have fewer children than their uneducated counterparts (Menashe-Oren & Sánchez-Páez, 2023). Furthermore, religious affiliation can also play a role in shaping fertility outcomes, as seen in the United States (McQuillan, 2004; Zhang, 2008), reducing the strength of the association between education and fertility. However, among women in sub-Saharan Africa, religion does not weaken the role of education in reducing fertility levels (Berger & Dasré, 2024). In addition, polygamous men in general have more children than monogamous and single men (Schoumaker, 2013a, 2019). The question remains whether the patterns observed among women and among migrant men—regarding education, religion and fertility patterns—also hold for a broader male population in sub-Saharan Africa, and whether these patterns vary across different male subgroups, such as religious affiliation or relationship status.

In summary, the gaps in the literature on education and fertility in sub-Saharan Africa highlight significant opportunities for further research. This thesis bridges these gaps by exploring the complex relationship between education, fertility behaviour, and union age gaps, by examining both male and female education in sub-Saharan Africa.

1.3. Research Aims and Objectives

As noted in the conceptual framework (Figure 1.1), this thesis frames education as central to fertility outcomes in relation to literacy skills, gendered norms (e.g., spousal age gaps), and factors such as religion and polygyny. Building on this framework, the dissertation focuses on these dimensions in low- and middle-income countries, with a particular emphasis on sub-Saharan Africa. The research spans across four interrelated aims, each progressively narrowing the focus from a broad global perspective to a specific regional and country-level analysis. The dissertation aims to answer critical questions about the role of education in fertility change, examining various aspects of educational attainment, literacy, male fertility and spousal age gaps within specific countries and regions.

Research Aim 1:

Firstly, this thesis provides comparable estimates of fertility rates by education level across low- and middle-income countries, focusing on trends in education-specific fertility rates across 41 African and 9 Latin American countries between 1970 and 2020.

The first publication, "A Bayesian Model for the Reconstruction of Education- and Age-Specific Fertility Rates: An Application to African and Latin American Countries", addresses this aim.

The targeted research question is:

- What are the levels and trends in education- and age-specific fertility rates across low- and middle-income countries?

Research Aim 2:

The second aim is to understand the relationship between literacy and fertility in 38 sub-Saharan African countries available within the DHS database. This study explores the relationship between literacy, independent of education, and both the timing of first births and completed fertility. This aim is crucial because in many sub-Saharan African countries, years of schooling do not always translate into literacy, particularly at the primary level. While education is widely linked to fertility decline, much less is known about whether literacy itself explains differences in age at first birth and completed fertility. Distinguishing the role of literacy from formal education allows us to assess whether functional skills, rather than schooling alone, are associated with fertility outcomes. This aim is explored in the paper "Age at First Birth, Completed Fertility, and Literacy Skills in sub-Saharan Africa."

The paper tackles the second research question:

- At a given level of education, is literacy associated with age at first birth and completed fertility in sub-Saharan African countries?

  Sub-questions under this research question include:

- Among women with no education and primary education, do literate women have fewer children and at a later age than non-literate women?
- Do literate women with primary education have the same mean age at first birth and completed fertility as secondary-educated women?
- Do we observe different or similar patterns in these relationships depending on the prevalence of literacy among women with a primary education in each country?
- Do years spent in schooling at the primary education level reduce or change the effects of literacy?

By focusing on literacy as a factor in fertility, the study aims to contribute new insights into the ongoing discussions on the role of education in fertility decline in the region.

Research Aim 3:

The third aim is to investigate how spousal age gaps vary by men's, women's, and couples' education levels in sub-Saharan Africa, with a particular focus on Ghana and Kenya. While education delays marriage and childbearing, the gendered nature of these trends, especially in terms of age differences between spouses, has been less studied in sub-Saharan Africa. This aim addresses patterns of variation in spousal age gaps by education, exploring whether gaps are narrower or wider across different educational groups.

This aim is explored in the paper "Shifting Spousal Age Gaps in Ghana and Kenya: Does Education Matter?" by addressing the following questions.

1. How have spousal age gaps changed in Ghana and Kenya from 1990-1994 to 2020-2024 survey period?

2. Does male education play a stronger role in reducing high age gaps than female or the couples' joint educational combinations?
3. To what extent do changes in educational composition versus partner selection behaviours explain the changes in the mean spousal age gap?

This aim is critical for understanding the broader implications of education on family formation dynamics in Ghana and Kenya, specifically, how education relates to social structures such as marriage and partnership age gaps. By focusing on Ghana and Kenya, this study presents comparative insights into the relationship between education and spousal age gaps in two sub-Saharan African countries with similar timelines of implementing UPE, yet different ideologies on family formation.

Research Aim 4:

The final aim situates male fertility within the conceptual framework, investigating how men's education relates to fertility levels, and assessing how this relationship varies by religion and relationship status in sub-Saharan Africa. It examines the associations between education, religious affiliation, relationship status and cohort male fertility across 36 sub-Saharan African countries. This particular aim explores whether education is associated with male fertility amidst other determinants such as religion and relationship status.

The paper "Education, religion, and male fertility in sub-Saharan Africa: A Descriptive Analysis" addresses this aim by answering the following research questions:

Research Question 4:

- What is the relationship between education and male fertility in sub-Saharan Africa?

  In answering this main research question, the study answers other questions about male fertility, such as:

- Does the association between education and male fertility differ by religion and relationship status in sub-Saharan Africa?

This research on male fertility broadens the existing understanding of fertility in sub-Saharan Africa.

This dissertation makes several contributions to the literature on education and fertility. These questions, addressed across the papers, form part of a unified argument: fertility transitions in high-fertility settings cannot be understood solely through educational attainment but require a disaggregated, gender-sensitive perspective that is both context- and country-specific.

1.4. Data sources

Data Source Overview

The four parts of this dissertation utilise different data sources to answer the research questions posed in the earlier sections of this dissertation. While each research aim and publication addresses distinct aspects of education and fertility, all four papers share a common theme and use the Demographic and Health Surveys (DHS) as a primary data source. The DHS, widely regarded as a relatively reliable and comprehensive dataset, provides nationally representative demographic and health information for low- and middle-income countries, making it an invaluable resource for studying fertility behaviour across diverse regions. This dissertation draws on data sources that differ in granularity and complexity, which makes it possible to analyse the multidimensional relationship between education and fertility. The specific datasets and their uses across the research papers are detailed below.

First Paper: Education-Specific Fertility Rates (Research Question 1)

The first paper relies on additional data sources from the United Nations World Population Prospects (UN WPP), the Wittgenstein Centre Human Capital Data Explorer (WIC), and the UN-benchmarked education-specific total fertility rates (ESTFR) for sub-Saharan African countries reported in the study by Yildiz et al. (2023). The first paper addresses the research question of how fertility rates differ by education level in low- and middle-income countries. The primary data source is the birth histories from the Individual (women's) Recode (IR) data (DHS) across 41 African and 9 Latin American countries. The study involves DHS waves completed by 2020. These birth histories provide detailed information on the total number of children women have had, their age at childbirth, and the education level attained, which are crucial for assessing the relationship between education and fertility.

In addition to the DHS birth histories, this study integrates data from the United Nations World Population Prospects (UN WPP) 2022 revisions, which provide total and age-specific fertility rates. The UN WPP is a highly reputable data source, updated every five years, and synthesises multiple data sources, including surveys and national registry data. The UN WPP's approach to estimating fertility rates is considered a global standard widely regarded as a reliable source for population and fertility projections (Raftery et al., 2014; United Nations Population Division, 2023).

Another critical dataset integrated into this study was the education-specific population projections from the Wittgenstein Centre Human Capital Data Explorer (WIC). WIC data are regularly updated to reflect global trends and projected future changes in demographic behaviours, including educational attainment. This dataset has been widely used in demographic studies to explore relationships between education, population growth, and fertility (Bagi & Karimi Aram, 2023; Maaløe et al., 2021; Wittgenstein Centre Human Capital Data Explorer, 2023).

The final data source comprises the UN-consistent estimates of education-specific total fertility rates (ESTFRs) from Yildiz et al. (2023). These estimates are based on a Bayesian framework that combines UN WPP fertility rates, DHS birth histories, and the Wittgenstein Centre's education data. Unlike the Bayesian model used in Paper 1, Yildiz et al. (2023) reconstruct total fertility rates by education level only. These estimates are incorporated in Paper 1 as benchmark inputs to regularise estimation and maintain UN-consistent estimates. At the time of the study, such estimates were available only for countries in sub-Saharan Africa.

Second Paper: Literacy and Fertility in sub-Saharan Africa (Research Question 2)

The second paper explores the relationship between literacy, age at first birth, and completed fertility in sub-Saharan Africa. This study draws on the DHS Birth and Individual Recode files for 38 sub-Saharan African countries. Similar to the first paper, this analysis draws on birth histories collected before 2020. In this case, the study focuses on cross-tabulated events, specifically, the total number of children women have had and the age at which they had their first child. The cross-tabulated events were collected using the R statistical software package, "survey" (Lumley, 2020). This package handles survey-weighted data and performs robust statistical analyses. The events of interest involved several factors, including education level, literacy level, and birth year. This approach constructs survey-weighted cross-tabulations of age at first birth and children ever born by literacy skills, enabling descriptive comparisons among women in sub-Saharan Africa.

Third Paper: Spousal Age Gaps and Education in sub-Saharan Africa (Research Question 3)

The third paper investigates how spousal age gaps vary by educational attainment in Ghana and Kenya, with particular attention to high gaps ($\geq$ 10 years). To examine this, the study employs Couples Recode (CR) files from the DHS, which contain data on the current age at marriage or union for men and women, including the educational attainment of both partners in married or cohabiting couples. The analysis involves calculating the spousal age gap by educational level for both females and males, as well as the mean spousal age gap for couples based on their dyadic (joint) educational attainment. Similar to the second paper, this study uses the "survey" package in R statistical software to calculate the weighted number of couples and analyse the age gaps. This approach enables robust estimations of the mean spousal age gap by education level, allowing the comparison of these gaps between Ghana and Kenya.

Fourth Paper: Education, religion, and male fertility in sub-Saharan Africa (Research Question 4)

The fourth paper examines the relationship between education and male fertility in 36 sub-Saharan African countries, focusing on birth cohorts from 1940 to 1979. To do so, the study utilises the Male Recode (MR) files from the DHS, which contain data on the total number of children men have, their educational attainments, their relationship status and their religious affiliations. The analysis involved calculating the mean number of children by birth cohort, religious affiliation, relationship status, and education level. The study analyses associations between these factors and male fertility using a Poisson regression. Similar to the second and third papers, the study employs the "survey" package in R statistical software to calculate the weighted mean number of children men have across the variables of interest.

1.5. Research Methodology and Approach

This thesis uses four quantitative approaches aligned to the four research questions: a Bayesian reconstruction (RQ1), Generalised Additive Models (GAMs; RQ2), a Kitagawa decomposition (RQ3), and Poisson regression (RQ4). Each subsection details the methods for the corresponding research question. The first research question, formulated in Research Aim 1, is addressed with a Bayesian reconstruction of education- and age-specific fertility for African and Latin American countries. This analysis contributes to understanding the historical context of education and fertility transitions in these regions. The second research question, explored in Research Aim 2, underscores the importance of literacy as an integral aspect of education and its relationship with fertility behaviour, age at first birth and completed fertility. The study uses Generalised Additive Models (GAMs) to explore these relationships. By focusing on literacy skills, this research highlights a novel perspective on how even low levels of formal education—at the primary level—may be associated with fertility outcomes in sub-Saharan Africa. The third and fourth research questions shift the focus to the intersection of education, gender, and marriage patterns, particularly the spousal age gap and male fertility, respectively, in sub-Saharan Africa. These analyses provide broader context for persistently high fertility levels in the region despite increasing educational attainment. The spousal age gap study uses a Kitagawa decomposition to quantify the contributions of shifts in the educational composition of unions and within-education differences to the overall change in the mean spousal age gap; the male-fertility study fits Poisson models to summarise associations between education and men's children ever born (CEB).

The dissertation investigates the relationship between education and fertility across various contexts. To maintain consistency throughout the dissertation and collection of papers, the definitions and classifications of education remain similar. The education categories used in the papers of this dissertation are from the primary data source, the DHS. The DHS categorises educational attainment into four groups: no education, primary education, secondary education, and higher education. These education classifications represent respondents' highest level of education (MEASURE DHS, 2008). In the first and second papers, the education groups are the exact classes of the DHS, and the papers borrow and use the four groups without alterations. In the third and fourth papers, to address potential problems with small sample sizes, the higher education levels (secondary and higher) are combined. The lower education categories—no education and primary education—remain consistent with DHS classifications.

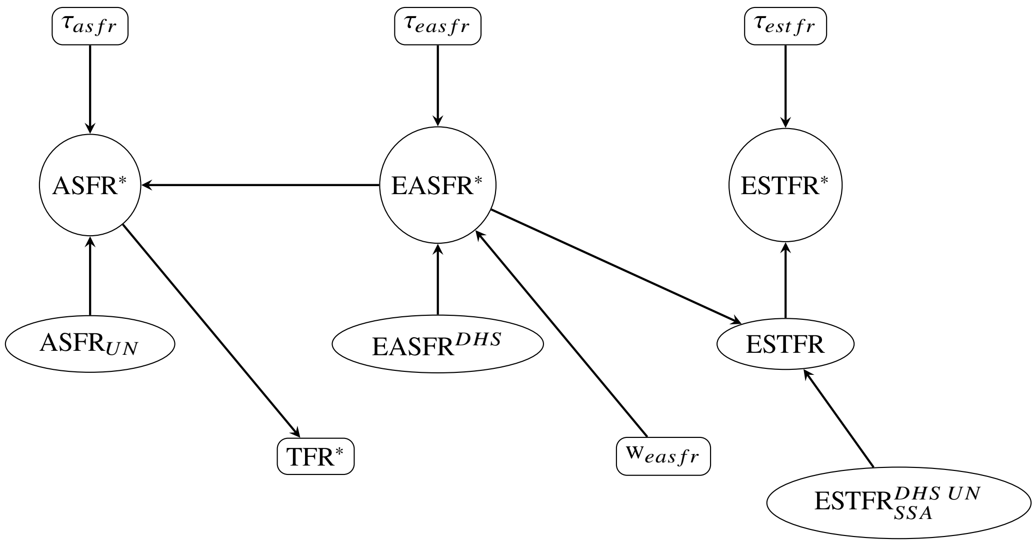
Addressing RQ1: Estimation of Education-Specific Fertility Rates.

This analysis uses a two-step statistical approach to estimate education-specific fertility rates. The calculation of fertility rates uses the primary data source, the Demographic and Health Surveys (DHS); however, as previously discussed, issues such as heaping can affect the accuracy of the estimates. Therefore, this study uses a multi-source approach to improve reliability. The first step applies Generalised Linear Models (GLMs) to the education-specific fertility rates derived from birth histories in the DHS surveys. The "tfr2" Stata module (Schoumaker, 2013b) calculates these estimated rates, which can cover periods as far back as 20 to 30 years before the survey, depending on the sample size of women. The resulting GLM predictions serve as inputs to the second step.

The second step involves integrating the GLM estimates into a Bayesian model, which also incorporates the total and age-specific fertility rates from the United Nations World Population Prospects and education-specific population sizes from the Wittgenstein Centre Human Capital Data Explorer (Lutz et al., 2018; United Nations Population Division, 2022). The Bayesian framework offers several advantages, particularly in dealing with poor-quality data using prior information to generate probabilistic estimates (Bijak & Bryant, 2016). Such prior information can include established demographic patterns, historical fertility trends, or parameter estimates from earlier studies and related datasets. By combining these priors with the observed data, the Bayesian approach produces probabilistic estimates that borrow strength from existing knowledge, helping to stabilise results and reduce the influence of random noise or missing values. The Bayesian approach is well-established in demographic research for projections and rate estimations, ensuring that the estimates are robust and reliable (Alkema et al., 2008, 2011; Hilton et al., 2019; Yildiz et al., 2023).

Figure 1.2 illustrates the Bayesian framework applied to RQ1, showing its components and data flow. In Figure 1.2, ASFR*, EASFR*, TFR*, and ESTFR* are the final outputs (reconstructed estimates) for age-specific fertility rates (ASFR), education- and age-specific fertility rates (EASFR), total fertility rates (TFR), and education-specific total fertility rates (ESTFR). In addition, ASFR_{UN} and EASFR^{DHS} are the estimates from the UN WPP and the GLM model in step one, respectively. $\text{ESTFR}_{SSA}^{DHS\ UN}$ represents the UN-consistent education-specific total fertility rates from the UN-DHS consistent model described in Yildiz et al. (2023) for sub-Saharan African (SSA) countries. The parameter w_{easfr} is the weight derived from the education-specific population sizes from WIC. Finally, parameters τ_{easfr}, τ_{asfr} and τ_{estfr} are Bayesian precision parameters informed by the input data, which govern uncertainty in the estimate. In the model, the parameters marked by asterisks are the unknown quantities to estimate; therefore, these, together with the precisions τs, follow a defined probabilistic function. The posteriors, ASFR*, EASFR*, TFR*, and ESTFR* are sampled via Markov chain Monte Carlo (MCMC), providing credible intervals for each estimate. The overall approach yields education-specific fertility rates that learn from multiple data sources and undergo rigorous sampling.

Figure 1.2: The Bayesian framework for education-specific rates.



Addressing RQ2: Relationship between Literacy, Education and Fertility Outcomes.

For RQ2, which investigates the relationship between education, literacy, first-birth timing, and completed fertility, the study uses Generalised Additive Models (GAMs). GAMs are an ideal choice for this analysis because they can model non-linear relationships between predictor variables (such as education and literacy levels) and outcomes of interest (such as age at first birth and total fertility). This flexibility is crucial, given the complex and often non-linear nature of fertility patterns (Wood, 2017).

The data for this analysis were drawn from the DHS, focusing on women who had their first births before the age of 40 and were between the ages of 40 and 50 at the time of the survey. The variables of interest include education level, literacy skills, birth year, age at first birth, and total number of children ever born. The "survey" package in R statistical software (Lumley, 2020) processes the survey-weighted data, ensuring that the analysis accounts for the complex survey design. The study analyses age at first birth and completed fertility separately to capture their relationships with education and literacy levels. GAMs are also less likely to overfit the data than conventional models, such as Poisson regression (Ellison et al., 2022; Wood, 2017), making them an effective tool for this analysis. While GAMs are uncommon in demographic studies, their ability to model complex relationships makes them ideal for this research, offering interpretability while accurately reflecting the complexities of fertility behaviours (Ellison et al., 2022).

The second research question uses literacy skills as an additional variable of interest. As with the education levels, the DHS administers literacy tests and categorises the responses for the survey waves. The DHS conducts literacy tests using four simple sentences, administered in multiple languages based on the country and region (MEASURE DHS, 2008). Interviewers are encouraged to probe further by asking additional questions to confirm the language in which the respondent is most fluent before administering the literacy test. This strategy helps ensure that the assessment is conducted in the most appropriate language, improving the accuracy of test results and making the DHS method more robust (Oye et al., 2016). In addressing the second research question, the literacy levels were literate, semi-literate, and illiterate. The literate group includes individuals who, according to the DHS, can read entire sentences or are classified as "reads easily" or "able to read the whole sentence", and other phrasings denoting the ability of the respondent to read the provided texts. The semi-literate group consisted of individuals classified by the DHS as "able to read some or part of the sentence". The illiterate group consists of individuals who cannot read the provided texts. By standardising educational and literacy classifications across the papers, the dissertation ensures a consistent approach to examining how education relates to fertility patterns in sub-Saharan Africa.

The modelling approach follows a multi-country model with country-specific fixed effects to account for contextual differences. This translates to the following for age at first birth,

$$\begin{aligned} E(\text{age at first birth}) &= \beta_0 + \beta_i \cdot \text{Education and literacy skill}_i + \beta_j \cdot \text{Country}_j \\ &+ \sum_p \beta_p (\text{s}(\text{Year of birth})_{\text{country}}). \end{aligned} \tag{1.1}$$

Similarly, for the total number of children ever born, the model follows:

$$E(\text{number of children ever born}) = \beta_0 + \beta_i \cdot \text{Education and literacy skill}_i + \beta_j \cdot \text{Country}_j + \sum_p \beta_p (\text{s}(\text{Year of birth})_{\text{country}}). \tag{1.2}$$

In addition, the modelling extends to literacy prevalence across sub-Saharan Africa. This approach explores whether the relationship between literacy skills and the mean age at first and total children ever born changes by literacy prevalence. The classification of each country is either "widespread", when ≥60% of women with a primary education are literate or "limited" otherwise. The 60% threshold follows the reported average literacy rates in sub-Saharan Africa (Roser & Ortiz-Ospina, 2016). The approach is:

$$E(\text{age at first birth}) = \beta_0 + \beta_i \cdot \text{Education and literacy skill}_i + \beta_j \cdot \text{Country}_{\text{literacy prevalence group}\,j} + \sum_p \beta_p (\text{s}(\text{Year of birth})_{\text{country}_{\text{literacy prevalence group}}}). \tag{1.3}$$

$$E(\text{number of children ever born}) = \beta_0 + \beta_i \cdot \text{Education and literacy skill}_i + \beta_j \cdot \text{Country}_{\text{literacy prevalence group}\,j} + \sum_p \beta_p (\text{s}(\text{Year of birth})_{\text{country}_{\text{literacy prevalence group}}}). \tag{1.4}$$

Finally, for RQ2, the models for years of schooling focus only on primary-educated women:

$$E(\text{age at first birth}) = \beta_0 + \beta_i \cdot \text{Education and literacy skill}_i + \beta_k \cdot \text{Years in school}_k + \beta_j \cdot \text{Country}_j + \sum_p \beta_p (\text{s}(\text{Year of birth})_{\text{country}}). \tag{1.5}$$

$$E(\text{number of children ever born}) = \beta_0 + \beta_i \cdot \text{Education and literacy skill}_i + \beta_k \cdot \text{Years in school}_k + \beta_j \cdot \text{Country}_j + \sum_p \beta_p (\text{s}(\text{Year of birth})_{\text{country}}). \tag{1.6}$$

In all models, the resulting outcomes are expected mean values.

Addressing RQ3: Relationship between Education and Spousal Age Gaps.

The third research question (RQ3) examines associations between education and the mean spousal age gap in sub-Saharan Africa, with a focus on Ghana and Kenya. To address this, the study applies the Kitagawa decomposition approach (Kitagawa, 1955), a method widely used in demographic research (e.g., Beaujouan et al., 2023), to separate the effects of changes in educational composition from changes in behaviour. This technique allocates the contribution of shifts in the composition of couples with an age gap of more than ten years—by male education, female education, and the couple's joint (dyadic) education level—and the contribution of behavioural changes within these groups to the overall change in mean spousal age gap between 1990–1994 and 2020–2024.

The decomposition equation in this study is:

$$
\begin{aligned}
\Delta M_{t_1 - t_0} &= \underbrace{\sum_e (P^e_{\geq 10, t_1} - P^e_{\geq 10, t_0}) \bar{M}^e_t}_{Structural\ effect} + \underbrace{\sum_e (M^e_{t_1} - M^e_{t_0}) \bar{P}^e_{\geq 10, t}}_{Rate\ effect}, \\
\bar{M}^e_t &= \frac{M^e_{t_0} + M^e_{t_1}}{2}, \\
\bar{P}^e_{\geq 10, t} &= \frac{P^e_{\geq 10, t_0} + P^e_{\geq 10, t_1}}{2}.
\end{aligned} \tag{1.7}
$$

The quantity $\Delta M_{t_1 - t_0}$ is the change in mean spousal age gap for either Ghana or Kenya between 2020–2024, t_1 and 1990-1994 t_0. M^e_t is the mean spousal age gap by each education level and $\bar{M}^e_t$ is the average of the mean spousal age gaps of 2020-2024, t_1 and 1990-1994 t_0 for each educational level. $P^e_{\geq 10, t}$ is the proportion of couples with ten or more years age gap by level of education, and $\bar{P}^e_{\geq 10, t}$ is the average proportion of couples with an age gap above ten years between the two survey periods by level of education.

The structural (compositional) effect captures how changes in the share of ≥10-year age-gap couples across education groups contribute to the overall change in the mean gap; the rate (within-group) effect captures how changes in the mean gap within education groups contribute to the overall change. By decomposing these changes, the analysis distinguishes the share of the observed shift in mean spousal gaps that is attributable to structural changes in the education distribution of high-age-gap couples versus behavioural changes among couples with similar educational profiles. This approach provides a more nuanced understanding of how education is associated with patterns in the spousal age gap over time. Focusing on Ghana and Kenya allows for a comparison of two countries with similar educational trajectories yet different family formation ideologies, offering broader insight into how men's, women's, and couples' education levels are associated with the dynamics of age gaps across sub-Saharan Africa.

In addition to the decomposition, the study also presents the absolute and percentage changes in mean spousal age gaps and proportions with an age gap above ten years between the first and last five-year survey periods. These are:

$$
\begin{aligned}
\Delta E_{t_{1,e} - t_{0,e}} \% &= \frac{E_{t_{1,e}} - E_{t_{0,e}}}{E_{t_0,e}} \cdot 100\%, \\
\Delta E_{t_1 - t_0} \% &= \frac{E_{t_1} - E_{t_0}}{E_{t_0}} \cdot 100\%.
\end{aligned} \tag{1.8}
$$

The calculations are for both mean quantities and by the three education levels (men's, women's, and couples').

Ultimately, this analysis contributes to a more comprehensive picture of how education relates to fertility and family formation in the region.

Addressing RQ4: Relationship between Education, Religion, Relationship Status and Male Fertility Level.

In research question four, the study examines the relationship between education, birth cohort, religious affiliation, relationship status and male fertility across 36 sub-Saharan African countries using a Poisson regression. Because the number of children men have follows a count data structure, applying a Poisson regression is beneficial in determining the nature of the association of these parameters (Cameron & Trivedi, 2013). The study also provides descriptive insights into these relationships. It reports the survey-weighted mean number of children ever born (CEB) for each ten-year birth cohort (from 1940 to 1979) using the "svyby" function in the R package "survey". The study presents the estimates by the level of education, religious affiliations, and relationship status. The groups for religious affiliations are Catholic, Protestant, Universal, Jehovah's Witness (JW), Muslim and None. The study joins all other Christian groups aside from Catholics and Jehovah's Witnesses as Protestants. The remaining groups (spiritual/traditional/other) are grouped under "Universal". Although Protestants, Catholics and Jehovah's Witnesses are all considered Christian, their teachings vary substantially from one another, thus meriting their unique categories (McQuillan, 2004). The categories for the relationship status are "single" (for men currently without partners), "monogamous" (men with only one wife/partner), and "polygamous" (men with more than one wife/partner).

The study tests a main Poisson model in addition to three alternative models run separately for each of the 36 sub-Saharan African countries. The main model follows:

$$\begin{aligned}\log(\lambda_i) = \quad & \beta_0 + \beta_j Cohort_j + \beta_k Religion_k + \beta_l Education_l \\ & + \beta_m Relationship_m + \beta_{kl} Religion_k Education_l. \end{aligned} \tag{1.9}$$

The other alternative models are:

$$\begin{aligned}\log(\lambda_i) = \quad & \beta_0 + \beta_j Cohort_j + \beta_k Religion_k + \beta_l Education_l \\ & + \beta_{kl} Religion_k Education_l. \end{aligned} \tag{1.10}$$

$$\begin{aligned}\log(\lambda_i) = \quad & \beta_0 + \beta_j Cohort_j + \beta_k Religion_k + \beta_l Education_l \\ & + \beta_m Relationship_m. \end{aligned} \tag{1.11}$$

$$\log(\lambda_i) = \quad \beta_0 + \beta_j Cohort_j + \beta_k Religion_k + \beta_l Education_l. \tag{1.12}$$

In the models for RQ4, λ_i corresponds to the expected mean children ever born from the survey-weighted means.

This thesis examines the relationship between education and fertility behaviour and outcomes in sub-Saharan Africa and Latin America using historical data. Drawing on large-scale surveys and international demographic datasets, Paper 1 reconstructs age- and education-specific fertility rates where direct data is lacking. Furthermore, it examines the associations involving education and literacy, relationship dynamics, gendered roles, and reproductive behaviour in Papers 2 to 4. The four studies show consistent associations between education and fertility, including later childbearing and differences linked to partnership dynamics and gendered roles. Together, these papers provide a multidimensional account of the fertility transition, grounded in data-scarce contexts, and underscore the value of treating education as both an outcome and a determinant of population change.

1.6. Structure of the papers

This dissertation comprises four distinct papers, each contributing to a broader understanding of the intersection between education and fertility in low- and middle-income countries, with a particular emphasis on sub-Saharan Africa. The first paper reconstructs education-specific fertility rates for Latin American and African nations. The second paper examines first-birth timing; the third investigates spousal age gaps in Ghana and Kenya. The fourth paper includes male education as a dimension in the sub-Saharan African fertility discourse.

The first paper, titled "A Bayesian Model for the Reconstruction of Education- and Age-Specific Fertility Rates: An Application to African and Latin American Countries", utilises a Bayesian approach to synthesise various data sources, including total fertility rates and educational demographics from the UN World Population Prospects, Wittgenstein Centre for Demography and Global Human Capital, and the Demographic and Health Surveys (DHS). The journal Demographic Research published the paper on November 10, 2023. The paper can be found at https://doi.org/10.4054/DemRes.2023.49.31

The second paper, "Age at First Birth, Completed Fertility, and Literacy Skills in sub-Saharan Africa," examines associations between literacy skills and fertility outcomes across sub-Saharan Africa, describing how literacy and education relate to fertility patterns. Submitted to Revue Quetelet on April 19, 2024, the article was resubmitted on August 8, 2025, following its second review round.

The third paper, "Shifting Spousal Age Gaps in Ghana and Kenya: Does Education Matter?" examines spousal age gaps in relation to educational attainment in Ghana and Kenya, with attention to gender differences in education and their association with age gaps. The paper was submitted to Demographic Research on 3 April 2025 and was accepted on 4 September 2025.

The fourth paper, "Education, religion, and male fertility in sub-Saharan Africa: A Descriptive Analysis", analyses the role of education, birth cohort, relationship status and religious affiliation in male fertility across sub-Saharan Africa. The journal Demographic Research published the paper as a Descriptive Finding on August 5, 2025. The paper is found here https://doi.org/10.4054/DemRes.2025.53.8

The dissertation concludes with a summary of the main findings from these papers and their broader implications for demographic transitions and educational policies in low- and middle-income countries.

References

Al Zalak, Z., & Goujon, A. (2017). *Assessment of the data quality in demographic and health surveys in Egypt* (tech. rep.). Vienna Institute of Demography Working Papers.

Alkema, L., Raftery, A. E., Gerland, P., Clark, S. J., & Pelletier, F. (2008). Estimating the total fertility rate from multiple imperfect data sources and assessing its uncertainty. *Center for Statistics and the Social Sciences, University of Washington*, *50*, 1–19.

Alkema, L., Raftery, A. E., Gerland, P., Clark, S. J., Pelletier, F., Buettner, T., & Heilig, G. K. (2011). Probabilistic projections of the total fertility rate for all countries. *Demography*, *48*(3), 815–839.

Amoo, E. O. (2017). Trends and determinants of female age at first marriage in sub-Saharan Africa (1990-2014): What has changed? *African Population Studies*, *31*(1).

Ausubel, J., Kramer, S., Shi, A. F., & Hackett, C. (2022). Measuring age differences among different-sex couples: Across religions and 130 countries, men are older than their female partners. *Population Studies*, *76*(3), 465–476.

Axinn, W. G., & Barber, J. S. (2001). Mass education and fertility transition. *American Sociological Review*, 481–505.

Bado, A. R., Guengant, J.-P., & Maga, H. I. (2022). Sub-Saharan Africa: Slow fertility transitions despite policy efforts. In *International handbook of population policies* (pp. 159–182). Springer.

Bagi, M., & Karimi Aram, N. (2023). Cohort replacement and familism in Iran. *Sociology of Social Institutions*, *10*(21), 127–158.

Barbieri, M., Hertrich, V., & Grieve, M. (2005). Age difference between spouses and contraceptive practice in sub-Saharan Africa. *Population*, *60*(5), 617–654.

Beaujouan, E., Zeman, K., & Nathan, M. (2023). Delayed first births and completed fertility across the 1940–1969 birth cohorts. *Demographic Research*, *48*, 387–420.

Berger, H., & Dasré, A. (2024). Religious affiliation, education, and fertility in sub-Saharan Africa. *World Development*, *184*, 106723.

Bijak, J., & Bryant, J. (2016). Bayesian demography 250 years after bayes. *Population Studies*, *70*(1), 1–19.

Bongaarts, J. (2003). Completing the fertility transition in the developing world: The role of educational differences and fertility preferences. *Population Studies*, *57*(3), 321–335.

Bongaarts, J. (2010). The causes of educational differences in fertility in sub-Saharan Africa. *Vienna Yearbook of Population Research*, 31–50.

Bongaarts, J. (2017). Africa's unique fertility transition. *Population and Development Review*, *43*, 39–58.

Bongaarts, J., & Casterline, J. (2013). Fertility transition: Is sub-Saharan Africa different? *Population and Development Review*, *38*(Suppl 1), 153.

Boserup, E. (1985). Economic and demographic interrelationships in sub-Saharan Africa. *Population and Development Review*, 383–397.

Caldwell, J. C. (1980). Mass education as a determinant of the timing of fertility decline. *Population and Development Review*, 225–255.

Caldwell, J. C., & Caldwell, P. (1990). High fertility in sub-Saharan Africa. *Scientific American*, *262*(5), 118–125.

Cameron, A. C., & Trivedi, P. K. (2013). *Regression analysis of count data*. Cambridge university press.

Canning, D., Raja, S., & Yazbeck, A. (2015, October 1). *Africa's demographic transition: Dividend or disaster?* https://doi.org/10.1596/978-1-4648-0489-2

Coale, A. J. (1989). Demographic transition. In *Social economics* (pp. 16–23). Springer.

DeRose, L. F., & Kravdal, Ø. (2007). Educational reversals and first-birth timing in sub-Saharan Africa: A dynamic multilevel approach. *Demography*, *44*(1), 59–77.

Dudel, C., & Klüsener, S. (2021). Male–female fertility differentials across 17 high-income countries: Insights from a new data resource. *European Journal of Population*, *37*, 417–441.

Duflo, E., Dupas, P., & Kremer, M. (2010). Education and fertility: Experimental evidence from Kenya [Publisher: Citeseer]. *Unpublished Manuscript, J-PAL/MIT. Cambridge, MA*. Retrieved December 19, 2023, from https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=5945f8ae78c5d95eb6ad8a21e70835393958357c

Durowaa-Boateng, A., Yildiz, D., & Goujon, A. (2023). A Bayesian model for the reconstruction of education- and age-specific fertility rates. *Demographic Research*, *49*, 809–848.

Duze, M. C., & Mohammed, I. Z. (2006). Male knowledge, attitude, and family planning practices in Northern Nigeria. *African Journal of Reproductive Health*, *10*(3), 53–65.

Ellison, J., Berrington, A., Dodd, E., & Forster, J. J. (2022). Investigating the application of generalized additive models to discrete-time event history analysis for birth events. *Demographic Research*, *47*, 647–694.

Feng, Y., & Ren, J. (2022). Within marriage age gap across countries. *Economics Letters*, *210*, 110190.

Ferré, C. (2009). Age at first child: Does education delay fertility timing? the case of Kenya. *The Case of Kenya (February 1, 2009). World Bank Policy Research Working Paper*, (4833).

Frye, M., & Lopus, S. (2025). The educational differentiation of African birth timing. *Studies in Family Planning*.

Glick, P., Handy, C., & Sahn, D. E. (2015). Schooling, marriage, and age at first birth in Madagascar [Publisher: Taylor & Francis]. *Population Studies*, *69*(2), 219–236.

Goujon, A., Lutz, W., & Kc, S. (2015). Education stalls and subsequent stalls in African fertility: A descriptive overview. *Demographic Research*, *33*, 1281–1296.

Grant, M. J. (2015). The demographic promise of expanded female education: Trends in the age at first birth in Malawi [Publisher: Wiley Online Library]. *Population and Development Review*, *41*(3), 409–438.

Harwood-Lejeune, A. (2001). Rising age at marriage and fertility in Southern and Eastern Africa. *European Journal of Population/Revue Européenne de Démographie*, *17*, 261–280.

Hertrich, V. (2017). Trends in age at marriage and the onset of fertility transition in sub-Saharan Africa. *Population and Development Review*, *43*, 112–137.

Hilton, J., Dodd, E., Forster, J. J., & Smith, P. W. (2019). Projecting UK mortality by using Bayesian generalized additive models. *Journal of the Royal Statistical Society Series C: Applied Statistics*, *68*(1), 29–49.

Kebede, E., Goujon, A., & Lutz, W. (2019). Stalls in Africa's fertility decline partly result from disruptions in female education. *Proceedings of the National Academy of Sciences*, *116*(8), 2891–2896.

Kirk, D., & Pillet, B. (1998). Fertility levels, trends, and differentials in sub-Saharan Africa in the 1980s and 1990s [Publisher: JSTOR]. *Studies in Family Planning*, 1–22.

Kitagawa, E. M. (1955). Components of a difference between two rates. *Journal of the American Statistical Association*, *50*(272), 1168–1194.

Kramer, S. (2020). Polygamy is rare around the world and mostly confined to a few regions. *Pew Research Center*.

Kyei, P. S., Agyei-Mensah, S., Casterline, J. B., & Bawah, A. A. (2025). Trends in spousal age difference at first marriage in sub-saharan africa. *Journal of Biosocial Science*, 1–17.

Kyei, P. S., & Bawah, A. A. (2024). Spousal age differences and women's contraceptive use in sub-Saharan Africa. *Contraception and Reproductive Medicine*, *9*(1), 45.

LeVine, R. A., LeVine, S., Schnell-Anzola, B., Rowe, M. L., & Dexter, E. (2011). *Literacy and mothering: How women's schooling changes the lives of the world's children*. Oxford University Press.

Lumley, T. (2020). Survey: Analysis of complex survey samples [R package version 4.0].

Lutz, W., Goujon, A., Kc, S., Stonawski, M., & Stilianakis, N. (2018). *Demographic and human capital scenarios for the 21st century: 2018 assessment for 201 countries*. Publications Office of the European Union.

Lutz, W., & Samir, K. (2011). Global human capital: Integrating education and population. *Science*, *333*(6042), 587–592.

Maaløe, N., Housseine, N., Meguid, T., Tellier, S., van Roosmalen, J., Meyrowitsch, D. W., & van den Akker, T. (2021). Trends in population health and demography. *The Lancet*, *398*(10300), 579–580.

Marston, M., Slaymaker, E., Cremin, I., Floyd, S., McGrath, N., Kasamba, I., Lutalo, T., Nyirenda, M., Ndyanabo, A., Mupambireyi, Z., et al. (2009). Trends in marriage and time spent single in sub-Saharan Africa: A comparative analysis of six population-based cohort studies and nine demographic and health surveys. *Sexually Transmitted Infections*, *85*(Suppl 1), i64–i71.

McQuillan, K. (2004). When does religion influence fertility? *Population and Development Review*, *30*(1), 25–56.

MEASURE DHS. (2008). Demographic and health surveys model woman's questionnaire with hiv/aids and malaria modules.

Menashe-Oren, A., & Sánchez-Páez, D. A. (2023). Male fertility and internal migration in rural and urban sub-Saharan Africa. *European Journal of Population*, *39*(1), 10.

Mugarura, A., Kaberuka, W., & Atuhaire, R. (2016). Factors determining the age at first birth in Uganda. *Issues in Scientific Research*.

Nathan, M., & Pardo, I. (2019). Fertility postponement and regional patterns of dispersion in age at first birth: Descriptive findings and interpretations. *Comparative Population Studies*, *44*.

Neels, K., Murphy, M., Bhrolcháin, M. N., & Beaujouan, É. (2017). Rising educational participation and the trend to later childbearing. *Population and Development Review*, *43*(4), 667.

Ní Bhrolcháin, M., & Beaujouan, É. (2012). Fertility postponement is largely due to rising educational enrolment. *Population Studies*, *66*(3), 311–327.

Nishimura, M., Ogawa, K., Sifuna, D., Chimombo, J., Kunje, D., Ampiah, J., Byamugisha, A., Sawamura, N., & Yamada, S. (2009). A comparative analysis of universal primary education policy in Ghana, Kenya, Malawi and Uganda. *Journal of International Cooperation in Education*, *12*(1), 143–158.

Notestein, F. W. (1945). Population-the long view. *Food for the World.*, 36–57.

Obeng Gyimah, S. (2003). A cohort analysis of the timing of first birth and fertility in Ghana. *Population Research and Policy Review*, *22*, 251–266.

Osili, U. O., & Long, B. T. (2008). Does female schooling reduce fertility? evidence from Nigeria. *Journal of Development Economics*, *87*(1), 57–75.

Oye, M., Pritchett, L., & Sandefur, J. (2016). Girls' schooling is good, girls' schooling with learning is better. *Background Paper for The Learning Generation. The Education Commission*.

Raftery, A. E., Alkema, L., & Gerland, P. (2014). Bayesian population projections for the United Nations. *Statistical Science: A Review Journal of the Institute of Mathematical Statistics*, *29*(1), 58.

Ritchie, H., Samborska, V., Ahuja, N., Ortiz-Ospina, E., & Roser, M. (2023). Global education.

Rodgers, J. L., Kohler, H.-P., McGue, M., Behrman, J. R., Petersen, I., Bingley, P., & Christensen, K. (2008). Education and cognitive ability as direct, mediating, or spurious influences on female age at first birth: Behavior genetic models fit to danish twin data. *American Journal of Sociology*, *114*(S1), S202–S232.

Roser, M., & Ortiz-Ospina, E. (2016). Literacy. *Our World in Data*.

Rutstein, S. O., & Rojas, G. (2006). Guide to dhs statistics. demographic and health surveys. *Maryland: ORC Macro Calverton*.

Schoumaker, B. (2011). Omissions of births in dhs birth histories in sub-Saharan Africa: Measurement and determinants. *Population Association of America*.

Schoumaker, B. (2013a). Levels and patterns of male fertility in sub-Saharan Africa. what can we learn from the demographic and health surveys? *Population Association of America*.

Schoumaker, B. (2013b). A stata module for computing fertility rates and tfrs from birth histories: Tfr2. *Demographic Research*, *28*, 1093–1144.

Schoumaker, B. (2014). *Quality and consistency of dhs fertility estimates, 1990 to 2012*. ICF International Rockville, Maryland.

Schoumaker, B. (2017a). African fertility changes. In *Africa's population: In search of a demographic dividend* (pp. 197–211). Springer.

Schoumaker, B. (2017b). Measuring male fertility rates in developing countries with demographic and health surveys: An assessment of three methods. *Demographic Research*, *36*, 803–850.

Schoumaker, B. (2019). Male fertility around the world and over time: How different is it from female fertility? *Population and Development Review*, 459–487.

Schoumaker, B. D., & Sánchez-Páez, D. A. (2024). Disruptions in educational progress and fertility dynamics by educational level: Unraveling the link between education and fertility stalls in Sub-Saharan Africa. *Population and Development Review*, *50*(1), 59–85.

Shapiro, D., & Gebreselassie, T. (2014). Marriage in sub-saharan africa: Trends, determinants, and consequences. *Population research and policy review*, *33*, 229–255.

Sharma, S., Akhtar, F., Singh, R. K., & Mehra, S. (2021). Early marriage and spousal age difference: Predictors of preconception health of young married women in Delhi, India. *Journal of Health Research*, *36*(6), 1118–1130.

Smith-Greenaway, E. (2015). Educational attainment and adult literacy: A descriptive account of 31 sub-Saharan Africa countries. *Demographic Research*, *33*, 1015.

Sobotka, T. (2017). Post-transitional fertility: The role of childbearing postponement in fuelling the shift to low and unstable fertility levels. *Journal of Biosocial Science*, *49*(S1), S20–S45.

Sserwanja, Q., Nuwabaine, L., Kamara, K., & Musaba, M. W. (2023). Determinants of quality contraceptive counselling information among young women in Sierra Leone: Insights from the 2019 Sierra Leone demographic health survey. *BMC Women's Health*, *23*(1), 1–9.

Tabutin, D., Schoumaker, B., Coleman, H., Dutreuilh, C., Reeve, P., Tovey, J., & van Hoorn Alkema, B. (2020). The demography of sub-Saharan Africa in the 21st century [Number: 2 Publisher: INED]. *Population*, *75*(2), 165–286.

Teller, C., & Hailemariam, A. (2011). *The demographic transition and development in Africa* (Vol. 10). Springer.

Tooley, J., & Dixon, P. (2005). Private education is good for the poor: A study of private schools serving the poor in low-income countries.

Tooley, J., & Dixon, P. (2006). 'De facto' privatisation of education and the poor: Implications of a study from sub-Saharan Africa and India. *Compare*, *36*(4), 443–462.

Tropf, F. C., & Mandemakers, J. J. (2017). Is the association between education and fertility postponement causal? the role of family background factors. *Demography*, *54*(1), 71–91.

United Nations Population Division. (2022). *Wpp2022: World population prospects 2022* [R package version 1.1-2]. http://population.un.org/wpp

United Nations Population Division. (2023). Population division data portal [Accessed: 2023-8-29]. https://population.un.org/dataportal/home

Van Bavel, J., Klesment, M., Beaujouan, E., Brzozowska, Z., alphabetical order), (Puur, A., Reher, D., Requena, M., Sandström, G., Sobotka, T., et al. (2018). Seeding the gender revolution: Women's education and cohort fertility among the baby boom generations. *Population studies*, *72*(3), 283–304.

Van Zanden, J. L. (2011). The malthusian intermezzo: Women's wages and human capital formation between the late middle ages and the demographic transition of the 19th century. *The History of the Family*, *16*(4), 331–342.

Vavrus, F. K., & Larsen, U. (2003). Girls' education and fertility transitions: An analysis of recent trends in Tanzania and Uganda*. *Economic Development and Cultural Change*, *51*, 945–975. https://api.semanticscholar.org/CorpusID:154839464

Wittgenstein Centre Human Capital Data Explorer. (2023). Wittgenstein centre human capital data explorer. https://dataexplorer.wittgensteincentre.org/wcde-v3/

Wood, S. N. (2017). *Generalized additive models: An introduction with R*. Chapman; Hall/CRC.

Yildiz, D., Wiśniowski, A., Brzozowska, Z., & Durowaa-Boateng, A. (2023). A flexible model to reconstruct education-specific fertility rates: Sub-Saharan Africa case study.

Zhang, L. (2008). Religious affiliation, religiosity, and male and female fertility. *Demographic Research*, *18*, 233–262.

2. Thesis Publications

2.1. A Bayesian model for the reconstruction of education- and age-specific fertility rates: An application to African and Latin American countries

The first publication was on November 10, 2023, as

Durowaa-Boateng, A., Yildiz, D., & Goujon, A. (2023). A Bayesian model for the reconstruction of education- and age-specific fertility rates. Demographic Research, 49, 809-848.

https://doi.org/10.4054/DemRes.2023.49.31

Abstract: Consistent and reliable education- and age-specific fertility rates for the past are difficult to obtain in developing countries, although they are needed to evaluate the relationship between women's education and fertility across periods and cohorts. We aim to fill the gap by reconstructing age-specific fertility rates by level of education for a large sample of African and Latin American countries from 1970 to 2020 in five-year steps. We developed a Bayesian framework to reconstruct age-specific fertility rates by level of education using prior information from the Demographic and Health Surveys (DHS) birth history module. We find that the Bayesian approach allows for estimating reliable education- and age-specific fertility rates using multiple rounds of the DHS surveys. The time series obtained confirms the main findings of the literature on fertility trends and age and education-specific differentials. From a methodological point of view, we show that the Bayesian reconstruction model allows for estimating missing data on fertility by levels of educational attainment. We propose an advanced statistical model which fills the gap in the time series when data are missing and provides complete and UN WPP-consistent EASFRs for 50 countries.

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Research Article

A Bayesian model for the reconstruction of education- and age-specific fertility rates: An application to African and Latin American countries

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Contents

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Research Article

A Bayesian model for the reconstruction of education- and age-specific fertility rates: An application to African and Latin American countries

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Abstract

BACKGROUND
Consistent and reliable time series of education- and age-specific fertility rates for the past are difficult to obtain in developing countries, although they are needed to evaluate the impact of women's education on fertility across periods and cohorts.

OBJECTIVE
We aim to fill the existing gap by reconstructing age-specific fertility rates by level of education for a large sample of African and Latin American countries from 1970 to 2020 in 5-year steps.

METHOD
We develop a Bayesian framework to reconstruct age-specific fertility rates by level of education using prior information from the birth history module of the Demographic and Health Surveys (DHS).

RESULTS
We find that the Bayesian approach allows for estimating reliable education- and age-specific fertility rates using multiple rounds of the DHS surveys. The time series obtained confirm the main findings of the literature on fertility trends and age- and education-specific differentials.

CONCLUSION
From a methodological point of view, we show that the Bayesian reconstruction model allows for estimating missing data on fertility by level of educational attainment. This

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information is key when we account for the role of education in fertility rates and assess the impacts of education policies in countries in Africa and Latin America.

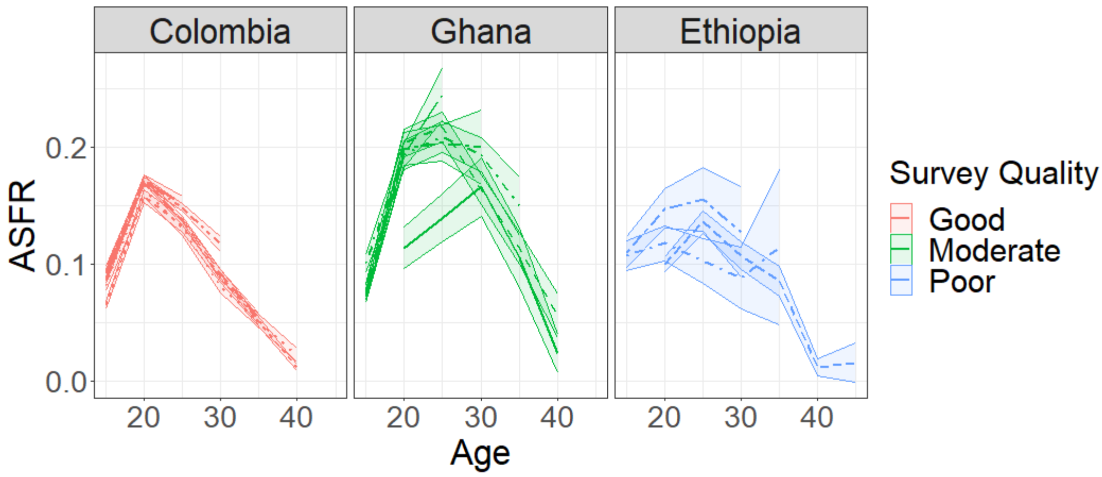
CONTRIBUTION
We propose an advanced statistical model which fills gaps in time series when data are missing, and provide complete and UN WPP-consistent age-specific fertility rates for 50 countries.

1. Introduction

The existence of a mostly negative relationship between women's education and fertility has been shown in many settings (e.g., Ahuja and Filmer 1995; Basu 2002; Bongaarts 2010; Brand and Davis 2011; Lutz and KC 2011; Martin and Juarez 1995; Weinberger, Lloyd, and Blanc 1989). The potential mechanisms at play are many, such as the fact that women with higher levels of education spend more years in school reduces their exposure to marriage and pregnancy at younger ages. They also tend to have better knowledge of and access to contraceptives to control their own fertility (e.g., Bongaarts 2010; Gebreselassie and Shapiro 2016). For example, in Latin America, Weinberger, Lloyd, and Blanc (1989) confirm that women with higher levels of education have fewer children and that 40%–67% (overall in Peru, Colombia, the Dominican Republic, and Ecuador) of the observed decline in fertility rates between the 1970s and 1980s was due to improvements in education. Bongaarts (2010) also explains the negative effects of education on fertility rates in sub-Saharan Africa by the greater demand for and use of modern contraceptives by women with higher levels of education. However, many unknowns remain about the precise pathways by which education affects fertility levels in different contexts and at different times. One of the main challenges in studying the relationship between education and fertility is the lack of comparable, consistent, and unbiased data on education- and age-specific fertility rates (EASFR), particularly in low-income countries.

Due to the limited availability of comprehensive and reliable registration systems, the main sources of data on fertility rates in high-fertility countries are various surveys (e.g., Demographic and Health Survey (DHS), Service Provision Assessment (SPA) survey, HIV/AIDS Indicator Survey (AIS), Malaria Indicator Survey (MIS)) and indirect estimates from the United Nations World Population Prospects (UN WPP 2022a) that use multiple data sources. The total fertility rates (TFR) and age-specific fertility rates (ASFR) published by the UN WPP on a regular basis are widely used. These estimates are consistent and allow for comparisons of fertility over time and across countries; as such they are considered trustworthy. However, these rates are not disaggregated by level of educational attainment. The Wittgenstein Center for Demography and Global Human Capital (WIC) publishes population projections and estimates by level of education based on data collected from multiple sources including the UN WPPs (WIC 2018), and assumptions about the future. However, the education- and age-specific fertility rates for past years are not estimated. Demographic surveys provide fertility rates for population sub-groups, including level of educational attainment. Among them, Demographic and Health Surveys (DHS) are the main and only source of fertility data in many low-income countries. However, like any survey, they can be subject to different levels of sampling error that often lead to inconsistencies, limiting comparison across countries and for the same country over time. Furthermore, for the most part they are not conducted at regular intervals, such as every five years. The most common inconsistencies have been attributed to birth omissions and displacements (e.g., Al Zalak and Goujon 2017; Pullum and Becker 2014; Schoumaker 2011, 2014). In an assessment of DHS data, Schoumaker (2014) categorizes most Latin American countries as having "good" or "moderate" data quality when available, while many African countries are categorized as having "poor" data quality, reporting different rates for the same periods across consecutive surveys (e.g., Ethiopia). Figure 1 presents the age-specific fertility rates of women with secondary education in the 1990–1995 period estimated by different rounds of the DHS surveys using the DHS birth history module. In countries with good data quality (e.g., Colombia), age-specific schedules are more complete and estimates are relatively consistent for the same years, even for different surveys (see Figure 1).

Figure 1: Quality of 1990–1995 data for secondary education ASFR by different DHS surveys[3]



[3] The 1990–1995 period and secondary education were selected due to the availability of multiple surveys and countries representing all three levels of data quality mentioned in Schoumaker (2014).

Regarding the lack of time series in demographic surveys, Schoumaker (2013) proposes a Poisson regression model to reconstruct both ASFR and TFR from different rounds of DHS surveys. The method estimates past fertility rates using the birth history module of the survey. While it fills the gaps, the estimates are not consistent with the UN WPP, which are widely used (and considered more reliable).

In this research we combine four datasets (UN WPP, WIC, estimates from Yildiz et al. 2023, and DHS) to produce reliable and consistent EASFRs over time and across countries that are compatible with the UN WPP ASFR, using a Bayesian model.

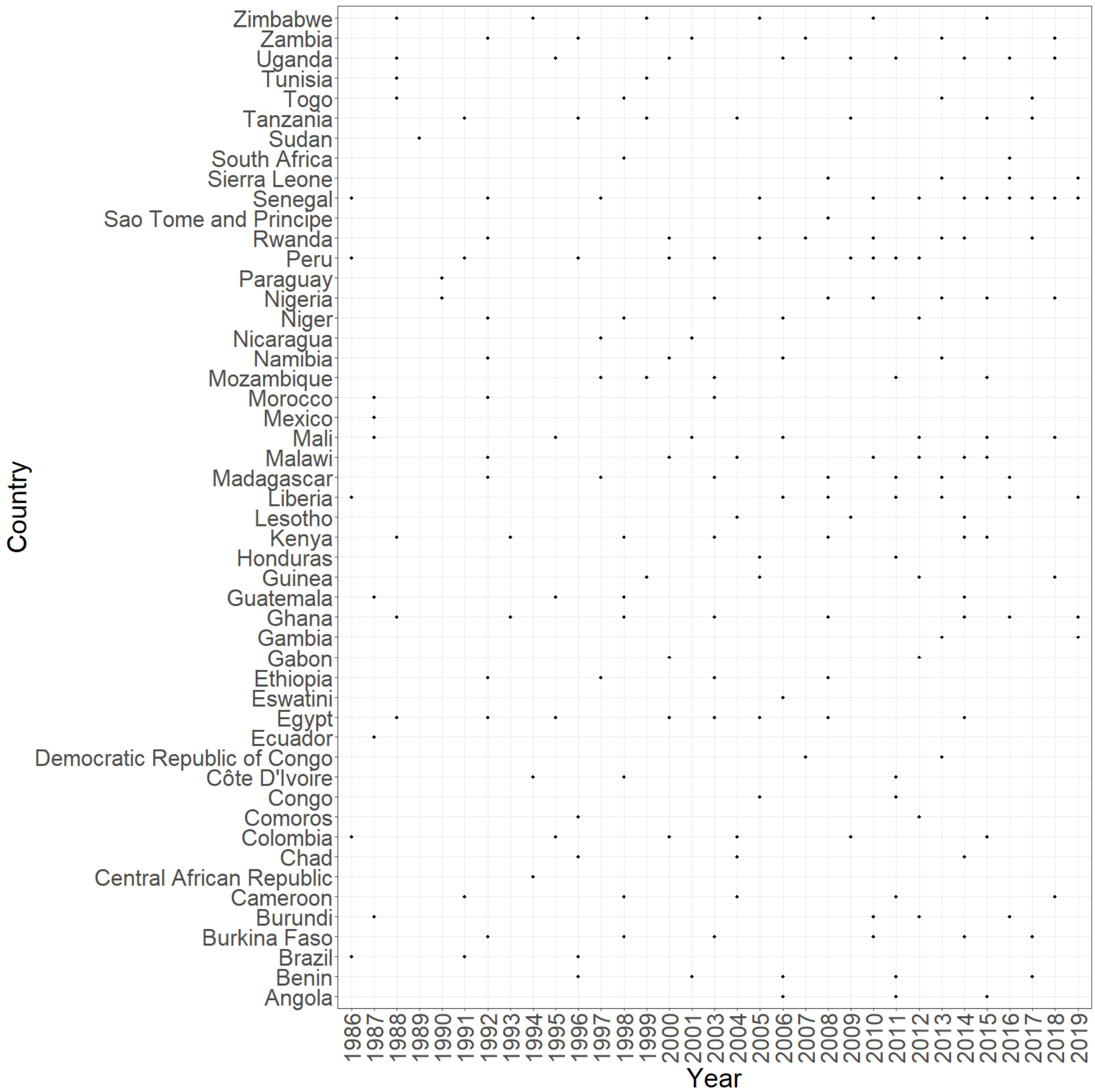
We follow Bijak and Bryant's (2016) recommendation to employ Bayesian methods in situations where sample sizes are small and the data quality is limited or poor. The Bayesian approach has been used in recent years in demographic estimates and population projections (e.g., Alkema et al. 2011; Bryant and Graham 2013; Ellison, Dodd, and Forster 2020; Hilton et al. 2019), including by the United Nations (UN) in recent rounds of population projections (Ševčíková, Raftery, and Gerland 2018). The modeling carried out in this work aims at developing a consistent and reliable dataset that will allow for a better understanding of the impact of education on fertility.

We estimate age-specific fertility rates for 41 DHS African and 9 Latin American countries by 4 levels of education between 1970–1975 and 2015–2020. Our paper contributes to the literature by proposing an advanced statistical model which fills the gap in the time series when data are missing, and by providing complete and UN WPP-consistent EASFRs for all 50 countries. We focus on Latin American and African countries in this analysis since to varying degrees they lack detailed, regular, and consistent data on EASFR for past years. Moreover, these two regions are interesting because the timing and pace of their demographic transitions are different. We plan to extend the research to more regions in the Global South in the future.

2. Data sources

We use four different data sources for this study: DHS, UN WPP (2022b), UN-consistent education-specific TFR from Yildiz et al. (2023), and WIC (2018). A total of 217 DHS conducted in Africa and Latin America are pooled for the analysis (see the full list of countries and surveys in Figure 2 and in Appendix A). Fertility rates are obtained from individual recode datasets in the DHS database (ICF 2004–2017). We consider 4 levels of education: No Education, Primary Education, Secondary Education, and Higher Education. These educational categories are collected in DHS surveys for each country and survey wave and are based on the highest level of education reported by the woman (The DHS program, n.d).

Figure 2: Countries and surveys collected, Africa and Latin America



Our analysis uses women's retrospective birth histories as collected in DHS rounds, focusing on reproductive ages 15 to 49 years. Since our goal is to reconstruct past fertility rates by level of education, for Latin American countries we focus on birth histories as far back as 30 years before the survey. For African countries the birth histories are collected for a shorter period of 15 years, given the lower quality of estimates due to long recall periods. The retrospective fertility rates by 5-year age groups and 5-year periods are obtained using the Stata 'tfr2' module, which provides fertility rates close to those published in the DHS reports (Schoumaker 2013). We utilize all available surveys with the exception of those conducted after 2020.

The second source of fertility data in our research is the 2022 edition of the UN WPP (2022b), which provides ASFRs for 5-year periods. The UN WPP collects fertility data, preferably on live births by age of mother, from civil registration systems, as well as all available data, including from the DHS. The UN WPP is updated every couple of years to achieve consistency over time and across different demographic statistics and includes new data sources which were previously omitted. This process makes the UN WPP a reliable source of global demographic data.

Further, Yildiz et al. (2023) estimate education-specific total fertility rates for sub-Saharan African countries from 1980 to 2015 by 5-year period using multiple data sources including WIC and UN WPP. The authors use a flexible hierarchical Bayesian model that allows education-specific estimates to vary with regard to degree of consistency with the UN data. The estimates are provided for sub-Saharan African countries only and focus on total fertility rates by education but not by age.

In addition to fertility rates, the size of the female population by level of education for the countries under consideration is obtained from the WIC data explorer (WIC 2018) through the ‘epop’ function in the ‘wcde’ R package (Abel 2021). These estimates are constructed using an iterative multi-dimensional cohort-component reconstruction model (IMCR) based on historical data on education and mortality (see Speringer et al. (2019) for more details). All data in our analysis concern women aged 15–49 years between 1970 and 2020.

3. Methodology

Various approaches within the Bayesian framework have been used to estimate fertility rates. For example, Ellison, Dodd, and Forster (2020), inspired by the Lexis diagram, developed a Bayesian technique to estimate cohort fertility where births were modeled to follow a Poisson distribution. Earlier, Bryant and Graham (2013) had modeled births as part of a sub-national population estimation model, in which births follow a Poisson distribution centered around expected births at the end of the period, similar to Ellison, Dodd, and Forster (2020). As mentioned above, Yildiz et al. (2023) used a flexible hierarchical Bayesian technique to estimate education-specific total fertility rates for sub-Saharan countries for the period 1980 to 2015 using existing sources. Finally, Alkema et al. (2011) estimated total fertility rates for 196 countries by considering their fertility transition phases. Each transition phase was modeled separately, taking into account the rate of decline. During the transition period, the TFR was modeled as the previous fertility rate minus the expected 5-year decrement, plus an error term. The 5-year decrement term follows a defined function while the error term follows a set of normal distributions when a set of conditions are met. For post-transition countries, the fertility rates were modeled as a normal distribution of a first-order autoregressive time series model.

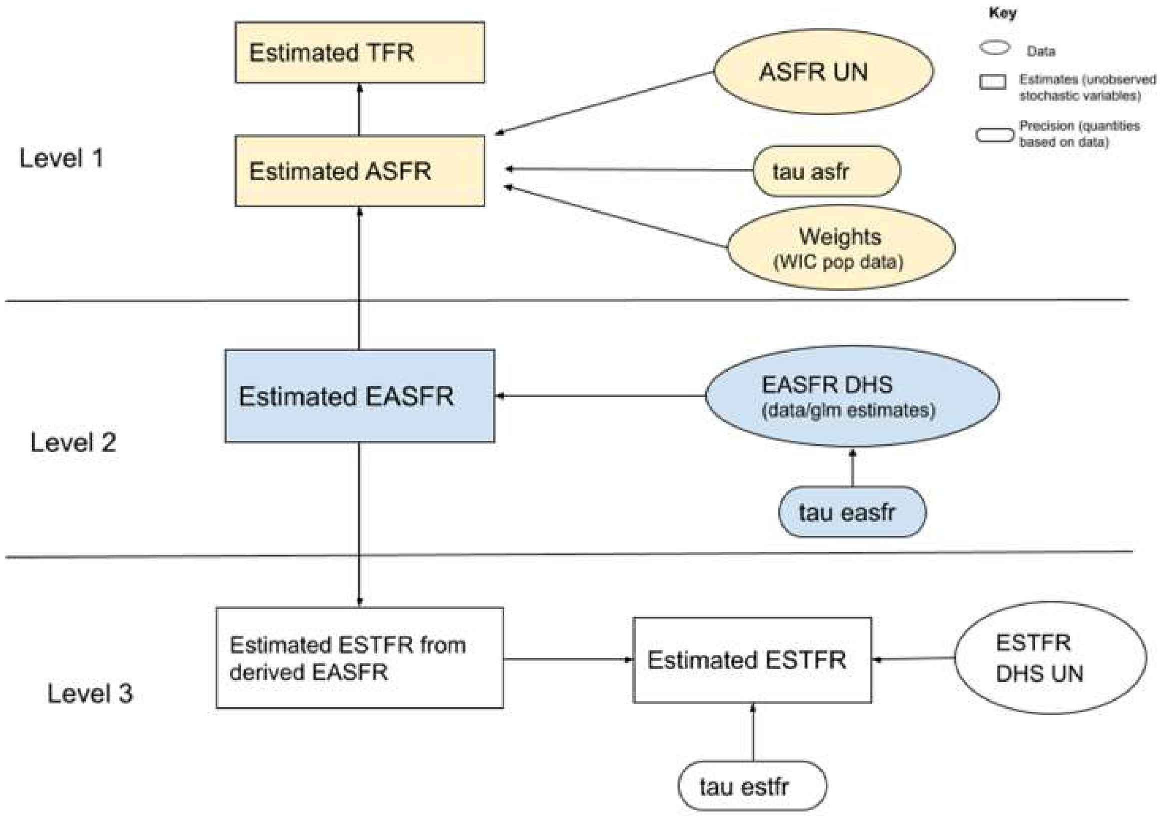
Our modeling framework consists of two main steps applied separately to African and Latin American countries. We improve and complement previous Bayesian approaches which did not integrate education and its impact on fertility rates, and did not estimate long time series of age-specific fertility rates. The first step in our approach is to estimate EASFRs for all DHS countries which enter the Bayesian model as initial values. To achieve this, we employ a generalized linear model (glm) with a Poisson link. The data for the glm model are the EASFRs obtained by the STATA tfr2 module using DHS birth histories. We adopt this approach to account for gaps in DHS estimates. We treat the glm estimates as the 'input' dataset for our Bayesian model.

The predicted estimates use information from the variables that influence fertility rates in our dataset, including the country itself, the number of women under consideration by 5-year period and age group, and their education level. In the event that a whole period schedule is missing (e.g., the 2015–2020 period for Latin American countries), the estimates use the aggregate effects of the period in question, including age group and country estimates (e.g., 2015–2020 period effect from all countries, educational effect, age group effects, country effects, and the specific interaction effects). To a large extent, the model learns from the other countries in the region since it uses all available information in the dataset to make estimates for the missing values. The glm model involves interaction terms between variables based on the assumption that the effects of these variables are not constant. The regression model for EASFR is defined as:

$$EASFR^{DHS} \sim Education + Age\ Group + Country + \text{Period} + Age\ Group * Country + Country * \text{Period} + Education * Age\ Group + \text{Period} * Age\ Group. \qquad (1)$$

Using the glm model, we estimate initial values of the EASFR between 1970–1975 and 2015–2020 in 5-year intervals. The estimates produced by the model logically do not match with the UN WPP ASFRs. Also, in the event of missing or poor-quality data, the model estimates higher values than expected by the trend; for example, creating an abrupt halt or reversal of the fertility decline during the missing period. To address these issues and ensure consistency with the UN WPP ASFR, we employ a Bayesian framework in the second step, as explained in the next paragraphs. We show a graphical representation of our model in Figure 3 and then provide mathematical notations. In Figure 3, all squares are estimated values, while ovals serve as input data and half-rounded rectangles are precisions. We present level 1 in light yellow, level 2 in light blue, and level 3 in white.

Figure 3: Graphical representation of the Bayesian model



The first level (Level 1) starts with benchmarking our estimated ASFRs against UN WPP ASFRs. In Equation 2, the estimated $ASFR^{estimates}$ are adjusted to the UN WPP ASFRs for each country for all 5-year periods making use of the precision parameter τ^{asfr}, the inverse of the variance. The variance parameter σ^{asfr^2} is fixed at the variance of the UN WPP ASFRs estimates. In other words, it is used to define the degree of consistency with the UN WPP ASFRs. An exercise to investigate the sensitivity of the estimates to this parameter is presented in Appendix B. Since the UN WPP ASFRs are themselves dependent on DHS data, to avoid repeating the same information in our Bayesian model we only include ASFRs from UN WPP. We then calculate $ASFR^{estimates}$ as a weighted total of the predicted/estimated $EASFR^{\,estimates}$ in Equation 3. The weights, w $_{cyae}$, are the ratio of the population of women in age group a by level of education e to the total population of women aged 15–49 years for each 5-year period y in country c according to WIC.

Level 1:

$$ASFR_{cya}^{UN} \sim N_{+}(ASFR_{cya}^{estimates}, \tau^{asfr}) \tag{2}$$

$$ASFR_{cya}^{estimates} = \sum_{e=1}^{4} \left(EASFR_{cyae}^{estimates} \times w_{\ cyae}\right) \tag{3}$$

$$\tau^{asfr} = 1/\sigma^{asfr^2} \tag{4}$$

In the second level (Level 2, Equation 5), the 'true EASFRs,' unobserved and reconstructed $EASFR_{cyae}^{estimates}$, are sampled from a half-normal distribution centered at the $EASFR_{cyae}^{DHS}$ estimates from the regression model in Step 1 (Equation 1). The standard deviation parameter $\sigma_{e=No\ education}^{easfr}$ is the standard deviation of the standard errors from the glm estimates and to a large extent captures the variations from the 'true EASFRs.' We capture standard errors by education level. We allow τ_{cyae}^{easfr} to follow a gamma distribution and produce estimates for each country, year, and education level. We use the same 'initial values,' obtained from the 'no education' category, $\sigma_{e=No\ education}^{easfr}$, for all education levels, because this category is the education level with the highest standard deviation estimate.

Level 2:

$$EASFR_{cyae}^{estimates} \sim N_{+}(EASFR_{cyae}^{DHS}, \tau_{cyae}^{easfr}) \tag{5}$$

$$\tau_{cyae}^{easfr} \sim G(1/\sigma_{e=No\ education}^{easfr}, 2\sigma_{e=No\ education}^{easfr^2}) \tag{6}$$

The third level (Level 3, Equation 7) estimates $ESTFR_{cye}^{estimates}$ (education-specific TFR) by sampling from a half-normal distribution centered on the $ESTFR_{cye}^{derived}$ estimates calculated in Equation 8 by summing the EASFRs estimated in Equation (5) over age groups and multiplying them by 5. The ESTFRs estimates provide a perspective on the evolution of the fertility differentials by level of education at the aggregate level. The parameter σ^{estfr} follows a half-normal distribution that centers around parameter η, which is the minimum ESTFR in the region from Equation (1), and has a standard deviation h, which is fixed at 50 to allow variations in our estimates.

Level 3:

$$ESTFR_{cye}^{estimates} \sim N_{+}(ESTFR_{cye}^{derived}, \tau^{estfr}) \tag{7}$$

$$ESTFR_{cye}^{derived} = \left(\sum_{a=15-19}^{45-49} EASFR_{cyae}^{estimates}\right) \times 5 \tag{8}$$

$$\tau^{estfr} = 1/\sigma^{estfr^2} \tag{9}$$

$$\sigma^{estfr} \sim N(\eta, h) \tag{10}$$

For African countries, $ESTFR_{cye}^{derived}$ are benchmarked to "UN-fully consistent" ESTFR estimates by Yildiz et. al (2023), which are almost identical to the UN TFRs, and thus level 3 is specified as:

$$ESTFR_{cye}^{un-estfr} \sim N_{+(0,10)}(ESTFR_{cye}^{derived}, \mu_{cye}^{estfr} \tag{11}$$

$$ESTFR_{\ cye}^{\ estimates} \sim N_{+(0,10)}(ESTFR_{\ cye}^{\ derived}, \mu_{cye}^{estfr}) \tag{12}$$

$$\mu_{cye}^{estfr} \sim G(\sigma^{estfr}, \sigma^{estfr\ 2}) \tag{13}$$

The parameter μ follows a gamma distribution of the standard deviation, σ, of the ESTFR UN-consistent estimates for 'Higher Education.'

The full specification of the prior distributions and sensitivity analysis are presented in Appendix B. Equations 7 to 10 pertain to Latin American countries and Level 3 does not benchmark against estimates by Yildiz et al. (2023), unlike Equations 11 to 13 for African countries. Since the estimates of EASFRs are new, the model was validated using a cross-validation approach by leaving out, at random, 5%, 10%, and 15% of the data, and testing the model estimates on the omitted data. We compared the different estimates from the cross-validation exercise and found that after leaving out varying degrees of data, the estimated values from the cross-validation fell within acceptable credible intervals. We provide details of this exercise in the supplementary material (a brief description of the supplementary material is provided in Appendix D and are available at www.populationafrica.org).

4. Results

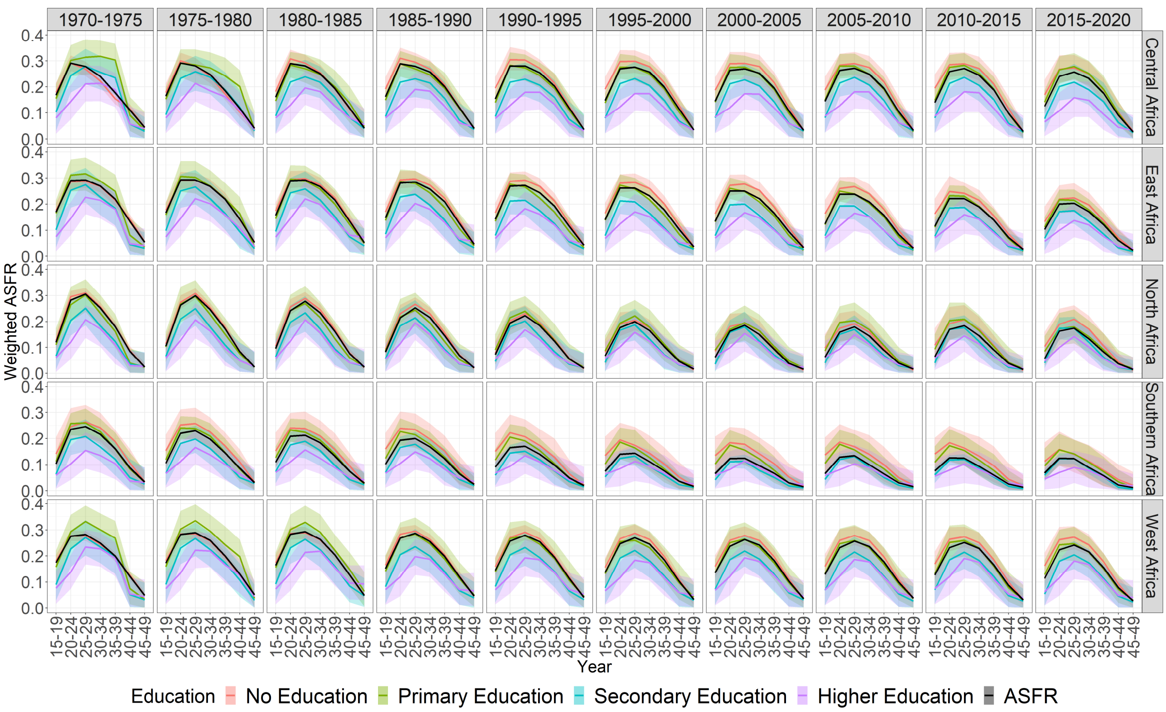
In this section we present estimates of the EASFRs for 1970–1975 to 2015–2020 for all countries under consideration, separately for Africa and Latin America, with a particular emphasis on the starting and end periods. Detailed estimates for all 5-year periods are presented in the supplementary material.

Weighted EASFRs, $EASFR_{ryae}$, are calculated for each region r in Africa, education level e, age group a, and period y as:

$$EASFR_{ryae} = \frac{\sum_{c\ in\ r} (EASFR_{cyae} \times Population_{cyae})}{\sum_{c\ in\ r} Population_{cyae}}$$

Figure 4 shows the weighted EASFRs for the African countries under consideration, grouped by UN regions. Although the lines between the subsequent levels of education sometimes cross, particularly at older ages – meaning that a higher level of education does not necessarily mean fewer children – each level of education (as categorized in this work) generally leads to lower fertility. In all regions and for all estimated years, women with secondary and/or higher education have the lowest weighted EASFR in their respective age groups, compared to women with primary education or less. Another general observation is that with increased levels of education the peak of the fertility curve occurs at older ages: this is particularly true for women with secondary or higher education in comparison with other education groups, throughout the reconstructed period. The low education levels of women in Africa translate into the average ASFR curve being very similar in terms of level and pattern to that of the ASFR of women without education in the earlier period, and with primary education in the later period. There are notable differences between regions, particularly between North and Southern Africa and the other African regions. In the former regions, the ASFR has already converged with the fertility pattern of secondary-educated women in the 1990s, indicating greater progress in education in these regions.

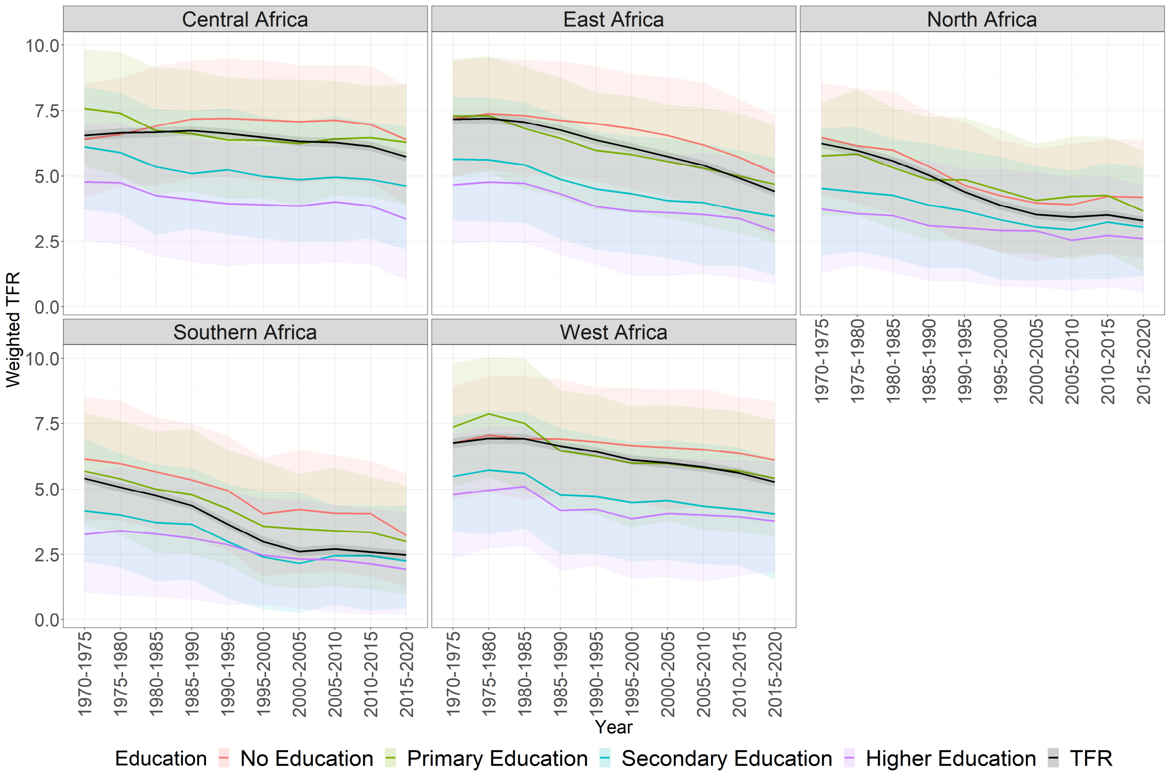
Figure 4: Weighted EASFRs and 95% CI by region, Africa, 1970–1975 to 2015–2020



Next, in Figure 5 we present weighted ESTFRs, $ESTFR_{ryae}$, estimated for each region in Africa r, education level e, age group a, and period y as:

$$ESTFR_{ryae} = \frac{\sum_{c\ in\ r} (ESTFR_{cyae} \times Population_{cyae})}{\sum_{c\ in\ r} Population_{cyae}}$$

Figure 5: Weighted ESTFRs and 95% CI by regions, Africa, 1970–1975 to 2015–2020



The ESTFRs in Central Africa and West Africa have been declining very slowly, with some periods of stagnation and even increase; e.g., for women with no education until 2010–2015 in Central Africa. The stalls in fertility decline have occurred among women in all education categories; e.g., for women with primary or higher education in the 1985–1995 period in West Africa. In these two regions, the difference in fertility between women with the highest level of education and the lowest level of education did not decline over time and was between 3.6 and 4.9 children per woman between 1970 and 2020. In East Africa, in most education categories the fertility decline is steadier than in the two other regions, especially concerning women with secondary and higher education. In this region since 2010–2015 there appears to have been an acceleration of the decreasing trend in the previous period, particularly visible for women without education. This trend is also visible in West Africa.

Figure 6 and Figure 7 show the EASFR estimates in African countries in the 1970–1975 and 2015–2020 periods. Most of the observed patterns in the regions are visible across countries, with the overall ASFRs closely following that of lower education groups.

Figure 6: EASFR and ASFR, Africa, 1970–1975

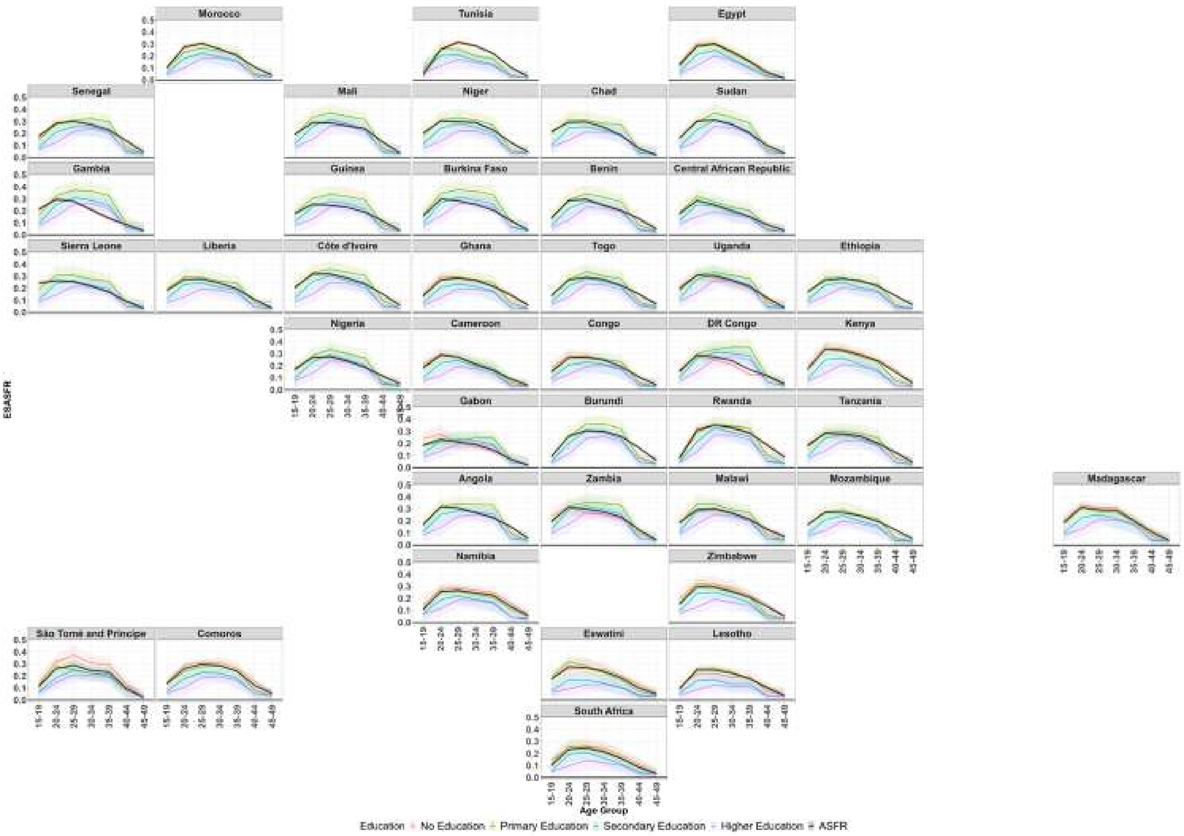
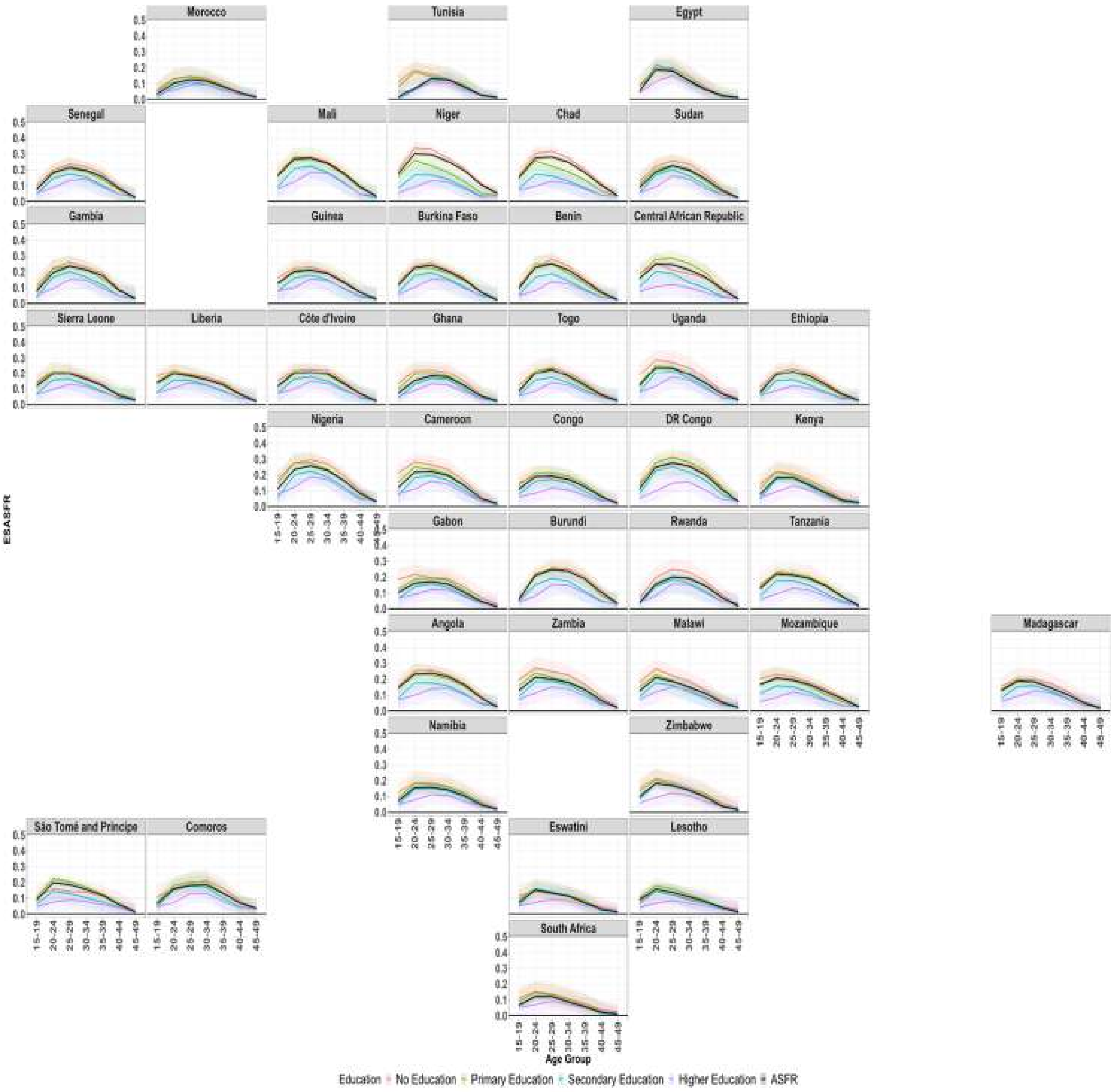


Figure 7: EASFR and ASFR, Africa, 2015–2020



In many African countries, overall ASFR and EASFR began to decline significantly from the 1980–1985 period (see supplementary material). On average, across all 5-year periods between 1970 and 2020, fertility among women with higher education peaked between the ages of 25 and 34 at around 0.2 to 0.3 children per woman. However, for women with secondary education, fertility was highest overall between the ages of 20 to 29 in all countries, at around 0.2 to 0.4 children per woman. For women with primary or no education, fertility peaked between the ages of 20–25, in general at around 0.3 to 0.4 children per woman.

Figure 8 shows the difference between 2015–2020 and 1970–1975 fertility rates for African countries. For many countries in the region the difference is negative, implying a decline in fertility rates. The biggest changes are among women with primary education, with a few exceptions. Among all levels of education other than no education, fertility rates have fallen for all ages (except ages 45–49) by around 0.1 children per woman, with the exception of Cameroon and the Central African Republic.

Figure 8: Difference between 2015–2020 and 1970–1975 for EASFR and ASFR, Africa

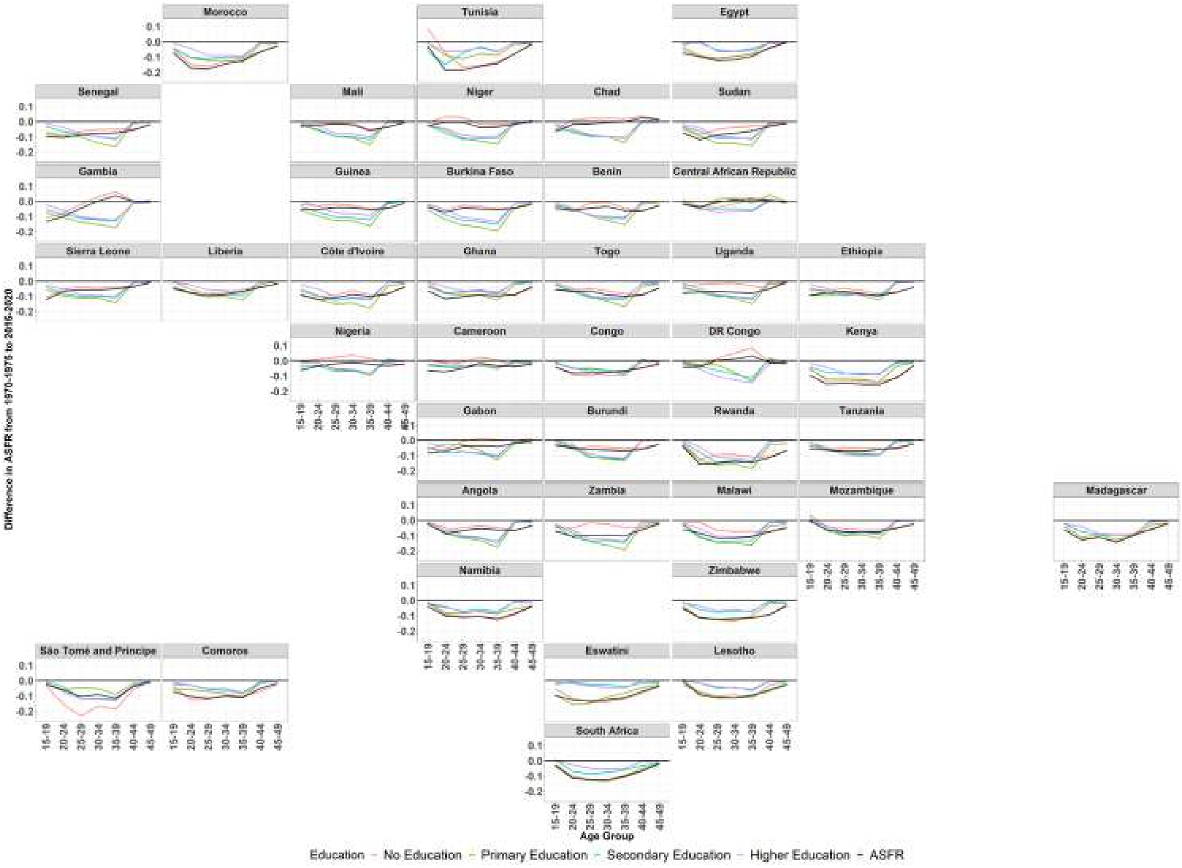
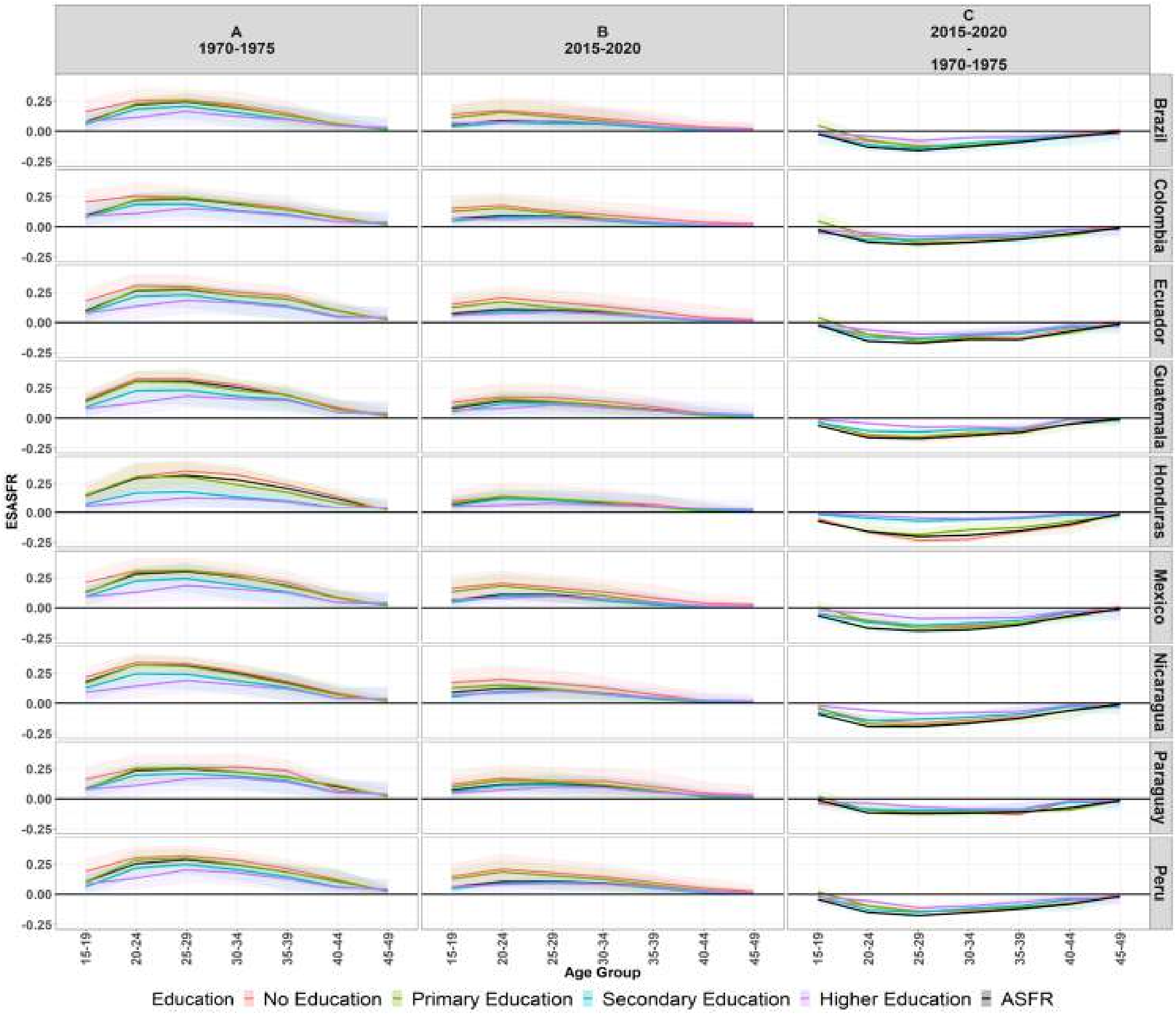


Figure 9 represents the 1970–1975 and 2015–2020 EASFR and the difference between the two periods for Latin America. The fertility transition and the education expansion occurred earlier in Latin America than in Africa (Bongaarts and Casterline 2013; Wils and Goujon 1998). As a result, compared with Africa the differentials in EASFR are larger in 1970–1975 and smaller in 2015–2020 (see Figure 9, panels A and

B, and Figure 8). Also, declines in overall ASFR and EASFR in Latin America are visible from the 1975–1980 period (see supplementary material). The overall ASFR appears to be largely influenced by the majority of women with primary education in Latin America from the 1970–1975 period until the 1990–1995 period, when the overall ASFR became more influenced by the large share of women with secondary and higher education. This is also reflected in Figure 9 for 1970–1975 and 2015–2020.

Figure 9: EASFR and ASFR, 1970–1975 (Panel A) and 2015–2020 (Panel B), and difference between 2015–2020 and 1970–1975 for EASFR and ASFR (Panel C), Latin American countries



In all the years under consideration, the fertility peak for women with higher education in Latin America occurred at 25 to 29 years old, at a level of around 0.2 children per woman in the 1975–1980 period (see supplementary material), declining to 0.07 children per woman in the 2015–2020 period. For women with secondary education, fertility peaked between the ages of 20 and 29, falling from around 0.25 children per woman in the 1975–1980 period to 0.06 children per woman in the 2010–2015 period. Women with primary education experienced a peak in fertility of around 0.32 children per woman in 1970–1975, declining to 0.14 children per woman in 2000–2005 at the ages of 20–24. Similarly, for women with no education at ages 20–24 we observed peak fertility rates of about 0.35 children in the 1990–1995 period, falling to 0.14 children in the 2015–2020 period.

Fertility rates in Latin America were significantly lower in the 2015–2020 period (Figure 9 panel B) than in the 1970–1975 period. Panel C shows differences in EASFR between 2015–2020 and 1970–1975. All age groups across all levels of education and countries saw their fertility rates decline. In Brazil, Colombia, Mexico, Ecuador, and Peru, women with secondary education between ages 15–19 and 20–24 saw a large decline of around 0.1 children per woman. In Peru and Brazil this decline reached almost 0.15 children per woman with a secondary education and was visible up until ages 25–29.

In all the studied countries, the smallest difference in fertility rates is observed among women with higher education. In Honduras, women with no education experienced a sharp drop in fertility rates, while in the other countries it was women with primary education who appeared to experience the largest decrease in fertility rates of all education groups.

5. Discussion and conclusion

Our analysis focuses on deriving and applying a methodology to estimate past total and age-specific fertility rates by level of education, for African and Latin American countries. Our aim is to fill a gap by providing a dataset for countries where historical good quality and consistent fertility data are scarce. We propose a Bayesian framework to reconstruct ASFRs by level of education and provide estimates for 41 African and 9 Latin American countries for 5-year periods from 1970 to 2020 using multiple data sources, combining more and less reliable datasets. Our estimates are UN WPP-consistent and provide complete age schedules by education level for past years which were previously not available for Africa and Latin America. However, a limitation is that it does not conscientiously model data quality by including the reliability of birth histories that happened a long time before the survey year. Another limitation is the inability to accurately validate the EASFRs, since these are the first estimates of their kind.

Nevertheless, we think these estimates of past fertility rates by age and level of education are essential for studying in detail the connection to the educational expansion and the role of education in the fertility transition. Furthermore, our estimates can be used to inform population projections. The analysis of the dataset resulting from the modeling confirms what has been demonstrated using existing data, as we will discuss below. These estimates support the general finding that women with higher education have lower fertility rates (e.g., Basu 2002; Bongaarts 2010; Weinberger, Lloyd, and Blanc 1989). The estimates across countries show that women with higher education have a relatively late onset of fertility as well as generally lower fertility rates. The model used can be expanded to other world regions within the DHS database to provide reliable estimates for other studies relating to fertility, population, and education.

Many countries in Africa (especially in sub-Saharan Africa) began their fertility transition in the 1980s (Bongaarts and Casterline 2013). Our estimate of education-specific rates in Africa before 1985 agrees with Cochrane (1979) and Martin (1995) in that in the least developed countries, where overall education levels were low, the achievement of some education (incomplete or completed primary) was sometimes reversely related to fertility. In countries like the Democratic Republic of the Congo, Gabon, and Nigeria, fertility rates for women with lower levels of education increased between the 1970–1975 and 2015–2020 periods. The analysis of the stalls in fertility decline show that they could in part be linked to the stalls in education progress (Goujon, Lutz, and KC 2015; Kebede, Goujon, and Lutz 2019). These countries have also experienced conflicts in the past, which can be followed by an increase in fertility in the early post-conflict period, as shown in the literature (e.g., Lindstrom and Berhanu 1999; Agadjanian and Prata 2002; Randall 2005).

Since Latin America was already undergoing the fertility transition at the beginning of our analysis, educational differentials in fertility rates were more visible. Our estimates in Latin America for periods before 2000–2005 are in line with the findings of Martin and Juarez (1995) concerning the relatively wide educational fertility differences. However, the differences appear to narrow rather drastically by the end of the period covered by our estimation exercise. The literature points out that the reduction in educational differentials and overall fertility rates could be attributed to government policies on public health and education, of women in particular (Rios-Neto and Guimarães 2014).

We also note a more pronounced decline in adolescent fertility rates by level of education when considering the differences between 1970–1975 and 2015–2020 in Latin American countries compared to African countries. The decrease in fertility differentials by educational level in many countries in Latin America and some countries in Africa supports the argument of Kravdal (2002), that as more women become educated and reduce their fertility in the community, women with lower levels of education tend to follow this behavior.

It is probable that education expansion has strongly contributed to the decrease in education-specific fertility rates between 1970–1975 and 2015–2020 in the countries under consideration. Santelli et al. (2017) report that Latin America and the Caribbean and sub-Saharan Africa regions spent about 4.4% and 4.6% of their GDP on education in 2012, respectively. This is 42% more than in 1990. As a result, on average the mean years of schooling for Latin American women aged 15 to 49 increased from 4.5 years in 1970 to 9.3 years in 2015. In Africa the increase started from much lower levels and was weaker, from 1.3 to 5.9 years (WIC 2018).

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References

Abel, G.J. (2021). WCDE: Download data from the Wittgenstein human capital data explorer [R package version 0.0.2]. https://CRAN.R-project.org/package=wcde.

Agadjanian, V. and Prata, N. (2002). War, peace, and fertility in Angola. *Demography* 39(2): 215–231. doi:10.1353/dem.2002.0013.

Ahuja, V. and Filmer, D. (1996). Educational attainment in developing countries: New estimates and projections disaggregated by gender. *Journal of Educational Planning and Administration* 10(3): 229–254.

Al Zalak, Z. and Goujon, A. (2017). Assessment of the data quality in Demographic and Health Surveys in Egypt. (Vienna Institute of Demography Working Papers 06/2017).

Alkema, L., Raftery, A.E., Gerland, P., Clark, S.J., Pelletier, F., Buettner, T., and Heilig, G.K. (2011). Probabilistic projections of the total fertility rate for all countries. *Demography* 48(3): 815–839. doi:10.1007/s13524-011-0040-5.

Basu, A.M. (2002). Why does education lead to lower fertility? A critical review of some of the possibilities. *World Development* 30(10): 1779–1790. doi:10.1016/S0305-750X(02)00072-4.

Bijak, J. and Bryant, J. (2016). Bayesian demography 250 years after Bayes. *Population Studies* 70(1): 1–19. doi:10.1080/00324728.2015.1122826.

Bongaarts, J. (2010). The causes of educational differences in fertility in sub-Saharan Africa. *Vienna Yearbook of Population Research* 8: 31–50. doi:10.31899/pgy3.1023.

Bongaarts, J. and Casterline, J. (2013). Fertility transition: Is sub-Saharan Africa different? *Population and Development Review* 38(Suppl 1): 153–168. doi:10.1111/j.1728-4457.2013.00557.x.

Brand, J.E. and Davis, D. (2011). The impact of college education on fertility: Evidence for heterogeneous effects. *Demography* 48(3): 863–887. doi:10.1007/s13524-011-0034-3.

Bryant, J.R. and Graham, P.J. (2013). Bayesian demographic accounts: Subnational population estimation using multiple data sources. *Bayesian Analysis* 8(3): 591–622. doi:10.1214/13-BA820.

Cochrane, S.H. (1979). Fertility and education: What do we really know? (World Bank Staff Occasional Papers 26). New York: World Bank.

Ellison, J., Dodd, E., and Forster, J.J. (2020). Forecasting of cohort fertility under a hierarchical Bayesian approach. *Journal of the Royal Statistical Society Series A: Statistics in Society* 183(3): 829–856. doi:10.1111/rssa.12566.

Gebreselassie, T. and Shapiro, D. (2016). *Education and fertility in sub-Saharan Africa: What do we really know?* Paper presented at PAA Annual Meeting, Washington, DC, March 31–April 2, 2016.

Goujon, A., Lutz, W., and KC, S. (2015). Education stalls and subsequent stalls in African fertility: A descriptive overview. *Demographic Research* 33(47): 1281–1296. doi:10.4054/DemRes.2015.33.47.

Hilton, J., Dodd, E., Forster, J.J., Smith, P.W., and Bijak, J. (2019). Forecasting fertility with parametric mixture models. arXiv preprint arXiv:1909.09545.

ICF (2004–2017). Demographic and Health Surveys (various) [Datasets]. Funded by USAID. Rockville, Maryland: ICF.

Kebede, E., Goujon, A., and Lutz, W. (2019). Stalls in Africa's fertility decline partly result from disruptions in female education. *Proceedings of the National Academy of Sciences* 116(8): 2891–2896. doi:10.1073/pnas.1717288116.

Kravdal, Ø. (2002). Education and fertility in sub-Saharan Africa: Individual and community effects. *Demography* 39(2): 233–250. doi:10.1353/dem.2002.0017.

Lindstrom, D.P. and Berhanu, B. (1999). The impact of war, famine, and economic decline on marital fertility in Ethiopia. *Demography* 36(2): 247–261. doi:10.2307/2648112.

Lutz, W. and KC, S. (2011). Global human capital: Integrating education and population. *Science* 333(6042): 587–592. doi:10.1126/science.1206964.

Martin, T.C. (1995). Women's education and fertility: Results from 26 Demographic and Health Surveys. *Studies in Family Planning* 26(4): 187–202. doi:10.2307/2137845.

Martin, T.C. and Juarez, F. (1995). The impact of women's education on fertility in Latin America: Searching for explanations. *International Family Planning Perspectives* 21(2): 52–80. doi:10.2307/2133523.

Pullum, T. and Becker, S. (2014). Evidence of omission and displacement in DHS birth histories. (Methodological reports vol. 11). Rockville: ICF International.

Randall, S. (2005). The demographic consequences of conflict, exile and repatriation: A case study of Malian Tuareg. *European Journal of Population/Revue Européenne de Démographie* 21(2/3): 291–320. doi:10.1007/s10680-005-6857-0.

Rios-Neto, E.L. and Guimarães, R.D.M. (2014). *The educational gradient of low fertility in Latin America*. Paper presented at PAA Annual Meeting, Boston, MA, May 1–3, 2014.

Santelli, J.S., Song, X., Garbers, S., Sharma, V., and Viner, R.M. (2017). Global trends in adolescent fertility, 1990–2012, in relation to national wealth, income inequalities, and educational expenditures. *Journal of Adolescent Health* 60(2): 161–168. doi:10.1016/j.jadohealth.2016.08.026.

Schoumaker, B. (2011). *Omissions of births in DHS birth histories in sub-Saharan Africa: Measurement and determinants*. Paper presented at PAA Annual Meeting, Washington, DC, March 31–April 2, 2011.

Schoumaker, B. (2013). A Stata module for computing fertility rates and TFRs from birth histories: tfr2. *Demographic Research* 28(38): 1093–1144. doi:10.4054/DemRes.2013.28.38.

Schoumaker, B. (2014). Quality and consistency of DHS fertility estimates, 1990 to 2012. Rockville, MD: ICF International.

Ševčíková, H., Raftery, A.E., and Gerland, P. (2018). Probabilistic projection of subnational total fertility rates. *Demographic Research* 38(60): 1843–1884. doi:10.4054/DemRes.2018.38.60.

Speringer, M., Goujon, A., KC, S., Potančoková, M., Reiter, C., Jurasszovich, S., and Eder, J. (2019). Global reconstruction of educational attainment, 1950 to 2015: Methodology and assessment. (Vienna Institute of Demography Working Papers 02/2019). Vienna: VID.

The DHS Program – Available Datasets. (n.d.). https://dhsprogram.com/data/available-datasets.cfm.

United Nations, Department of Economic and Social Affairs, Population Division (2022a). World Population Prospects 2022: Data Sources. (UN DESA/POP/2022/DC/NO. 9).

United Nations, Department of Economic and Social Affairs, Population Division. (2022b). wpp2022: World population prospects 2022 (R package version 1.1-2) [Computer software]. The Comprehensive R Archive Network. Available from https://population.un.org/wpp.

Weinberger, M.B., Lloyd, C., and Blanc, A.K. (1989). Women's education and fertility: A decade of change in four Latin American countries. *International Family Planning Perspectives* 15(1): 4–28. doi:10.2307/2133273.

WIC – Wittgenstein Centre for Demography and Global Human Capital (2018). Wittgenstein Centre Data Explorer Version 2.0. Available at: https://www.wittgensteincentre.org/dataexplorer.

Wils, A. and Goujon, A. (1998). Diffusion of education in six world regions, 1960–90. *Population and Development Review* 24(2): 357–368. doi:10.2307/2807979.

Yildiz, D., Wisniowski, A., Brzozowska, Z., and Durowaa-Boateng, A. (2023). A flexible model to reconstruct education-specific fertility rates: Sub-Saharan Africa case study. (Vienna Institute of Demography Working Papers 02/2023). Vienna: VID. doi:10.1553/0x003e65e0.

Appendix A: List of countries and surveys

Table A-1: List of countries and their survey years

Country	Survey year											
Angola	2006	2011	2015									
Benin	1996	2001	2006	2011	2017							
Brazil	1986	1991	1996									
Burkina Faso	1992	1998	2003	2010	2014	2017						
Burundi	1987	2010	2012	2016								
Cameroon	1991	1998	2004	2011	2018							
Central African Republic	1994											
Chad	1996	2004	2014									
Colombia	1986	1995	2000	2004	2009	2015						
Comoros	1996	2012										
Congo	2005	2011										
Côte D'Ivoire	1994	1998	2011									
DR Congo	2007	2013										
Ecuador	1987											
Egypt	1988	1992	1995	2000	2003	2005	2008	2014				
Eswatini	2006											
Ethiopia	1992	1997	2003	2008								
Gabon	2000	2012										
Gambia	2013	2019										
Ghana	1988	1993	1998	2003	2008	2014	2016					
Guatemala	1987	1995	1998	2014								
Guinea	1999	2005	2012	2018								
Honduras	2005	2011										
Kenya	1988	1993	1998	2003	2008	2014	2015					
Lesotho	2004	2009	2014									
Liberia	1986	2006	2008	2011	2013	2016	2019					
Madagascar	1992	1997	2003	2008	2011	2013	2016					
Malawi	1992	2000	2004	2010	2012	2014	2015					
Mali	1987	1995	2001	2006	2012	2015	2018					
Mexico	1987											
Morocco	1987	1992	2003									
Mozambique	1997	1999	2003	2011	2015							
Namibia	1992	2000	2006	2013								
Nicaragua	1997	2001										
Niger	1992	1998	2006	2012								
Nigeria	1990	2003	2008	2010	2013	2015	2018					
Paraguay	1990											
Peru	1986	1991	1996	2000	2003	2009	2010	2011	2012			
Rwanda	1992	2000	2005	2007	2010	2013	2014	2017				
Sao Tome and Principe	2008											
Senegal	1986	1992	1997	2005	2010	2012	2014	2015	2016	2017	2018	2019
Sierra Leone	2008	2013	2016	2019								
South Africa	1998	2016										
Sudan	1989											
Tanzania	1991	1996	1999	2004	2009	2015	2017					
Togo	1988	1998	2013	2017								
Tunisia	1988	1999										
Uganda	1988	1995	2000	2006	2009	2011	2014	2016				
Zambia	1992	1996	2001	2007	2013	2018						
Zimbabwe	1988	1994	1999	2005	2010	2015						

Appendix B: Prior distributions and sensitivity analysis

We explored different characterizations of the parameter ν and how it changed the estimation of EASFRs for both the Latin America and Africa models. We keep the model described in Equations 2 to 4 and 8 to 10 and change the values in Equations 5 and 6.

We identify our model described in the text as the 'Main Model' for both the Latin American and African cases. In Model 1 we define the parameter ν as the standard deviation of the standard error of the glm estimates by country *c*, year *y*, and age group *a* and

$$\tau_{cya}^{easfr} \sim G(1/\sigma_{cya}^{easfr^2}, \sigma_{cya}^{easfr^2})$$

In Model 2 we express σ as the standard deviation of the standard error of the glm estimates by education level only. Then,

$$\tau_{e}^{easfr} \sim G(1/\sigma_{e}^{easfr^2}, \sigma_{e}^{easfr^2})$$

In Model 3, σ is the standard deviation of the standard error of the glm estimates by level of education only. However,

$$\tau_{e}^{easfr} \sim G(1/\alpha_{e}^{easfr}, \sigma_{e}^{easfr^2})$$

where α_{e}^{easfr} is the mean of the standard errors of the glm estimates by only level of education.

In Model 4, we define σ as the standard deviation of the standard errors of the glm estimates. The following are specified for Model 4:

$$\tau^{easfr} \sim G(1/\sigma^{easfr^2}, \sigma^{easfr^2})$$

We define the following in Model 5:

$$\tau \sim G(1/\sigma^{easfr^2}, \sigma^{easfr^2})$$

where σ is now the standard deviation of the estimates from the glm model in Step 1.

We describe Model 6 as:

$$\tau^{easfr} \sim G(\beta_1, \beta_2)$$

and β_1=$(\sigma/\alpha)^2$, where ν is the standard deviation of the standard errors from the glm estimates and α is the mean of the standard errors of the glm estimates. Similarly, β_2=$(\sigma)^2/\alpha$.

Finally, in Model 7 we estimate ν as the standard deviation of the standard errors of the glm estimates by each country, year, and education level. We specify the following;

$$\tau_{cye}^{easfr} \sim G(1/\sigma_{cye}^{easfr^2}, \sigma_{cye}^{easfr^2})$$

In Figures B-1 and B-2, we compare the estimates of the tfr2 module's DHS education-specific estimates against the described models to compare how close our models' estimations are to those of DHS.

Figure B-1: Comparison of results of different models for age-specific fertility rates by level of education for Africa

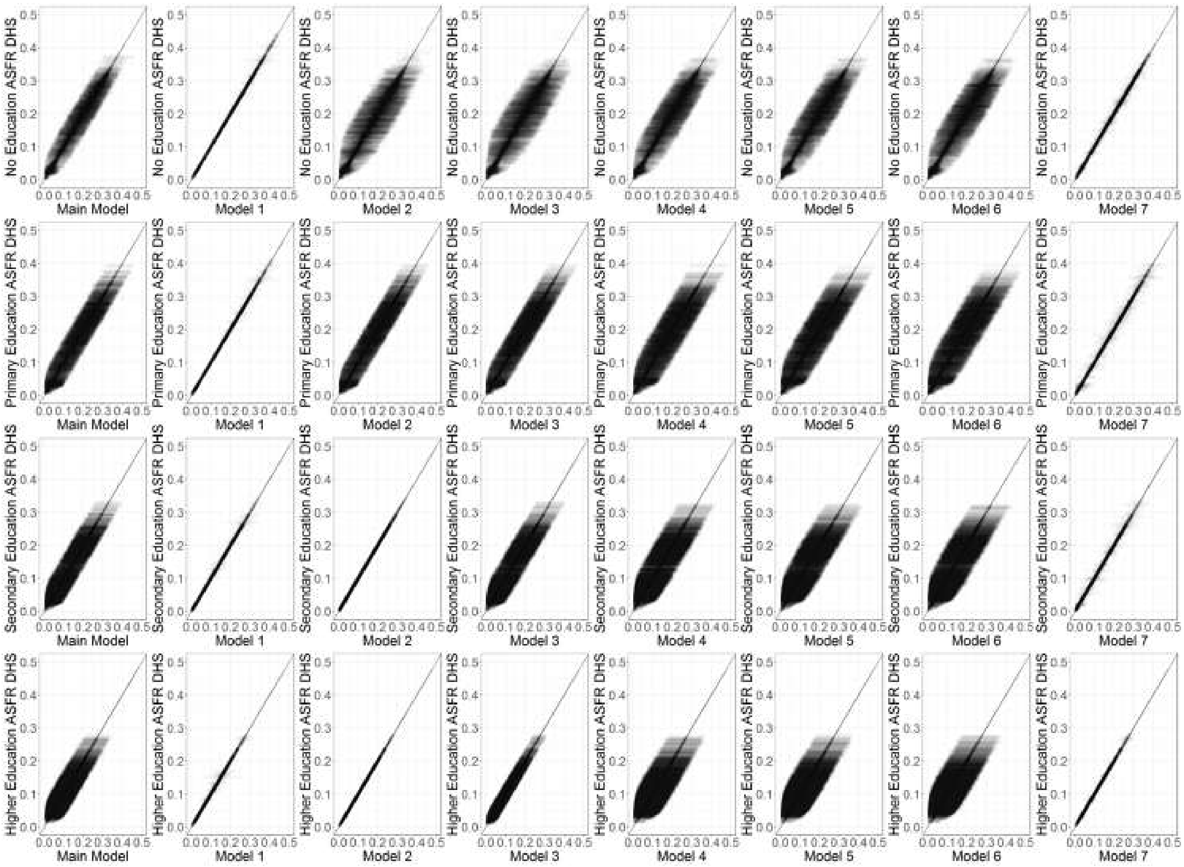
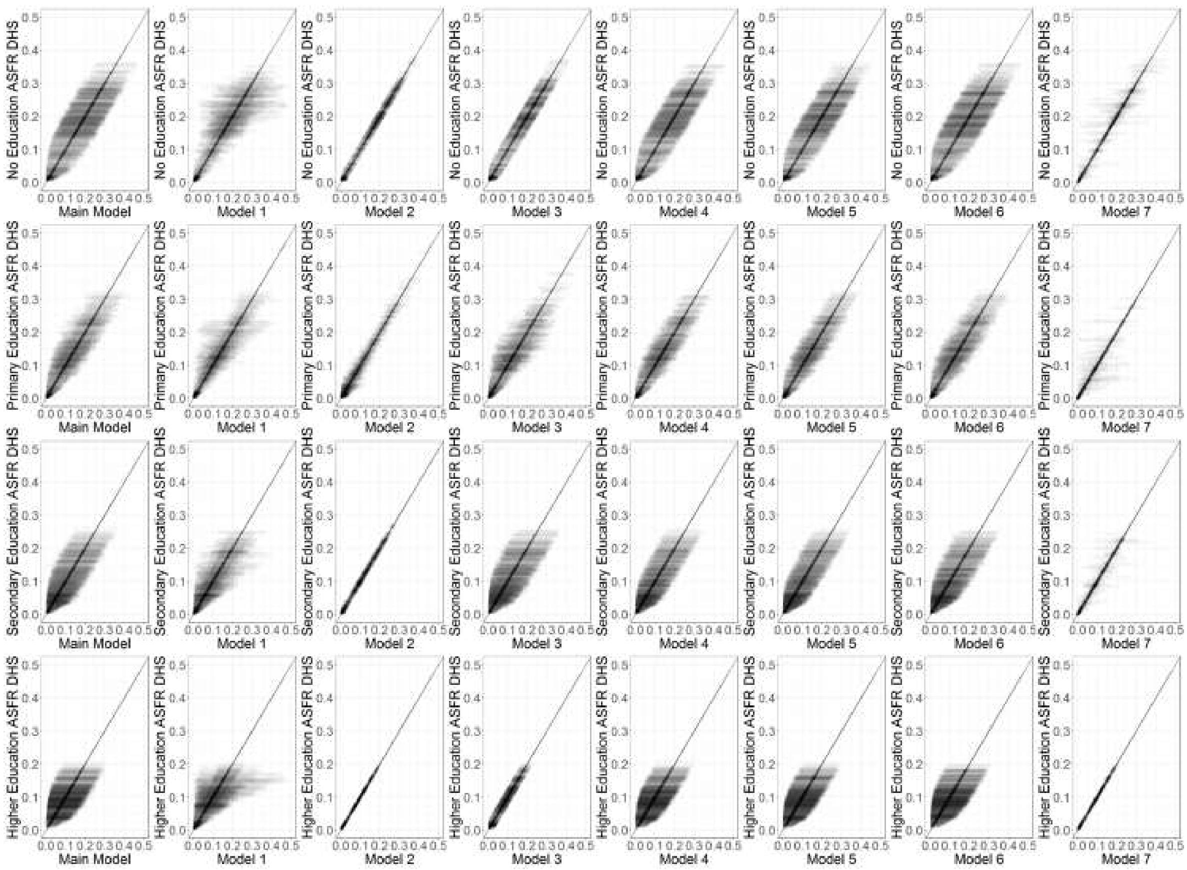


Figure B-2: Comparison of results of different models for age-specific fertility rates by level of education for Latin America



Appendix C: Differences between no education group and other levels of education

Figure C-1: Differences in education-specific, age-specific fertility rates, 1970–1975

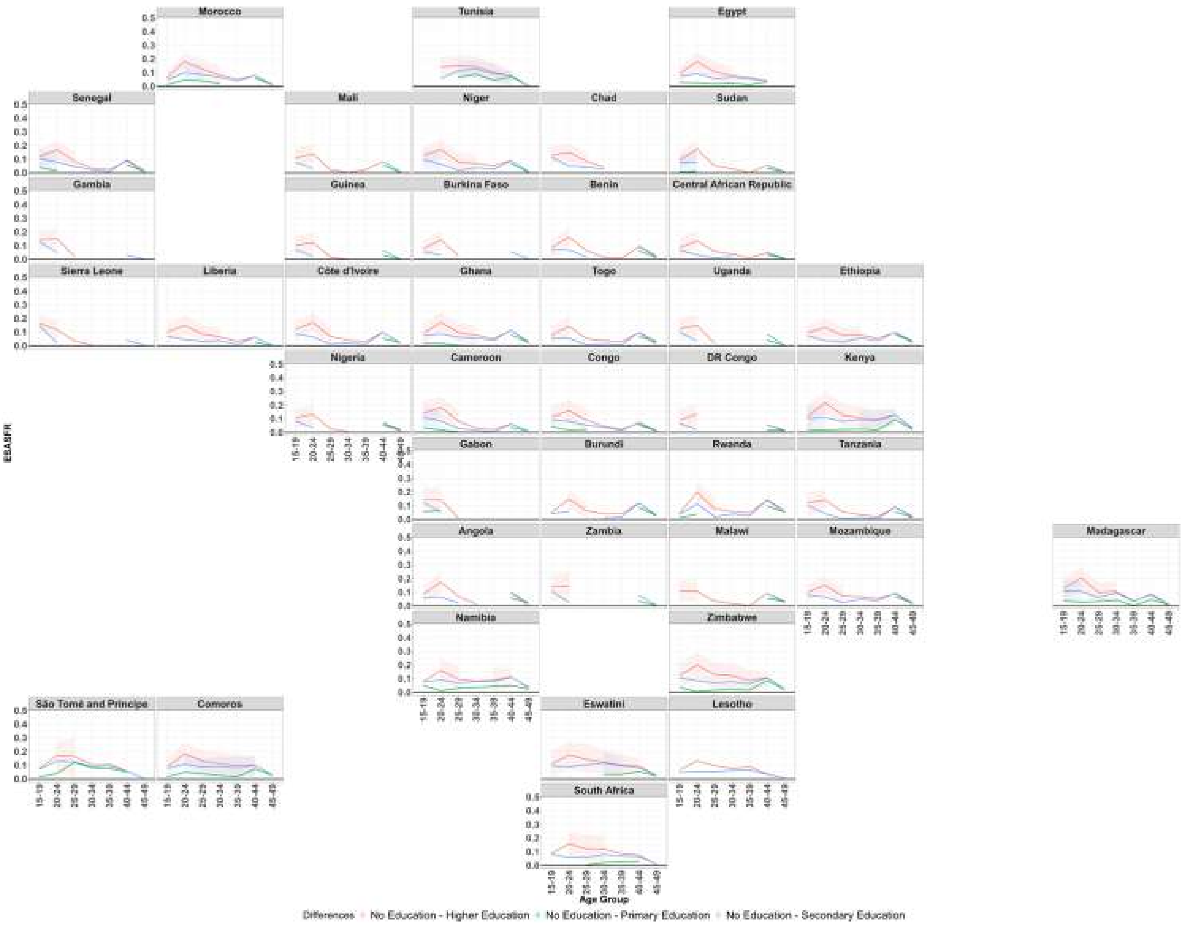


Figure C-2: Differences in education-specific, age-specific fertility rates, 1970–1975

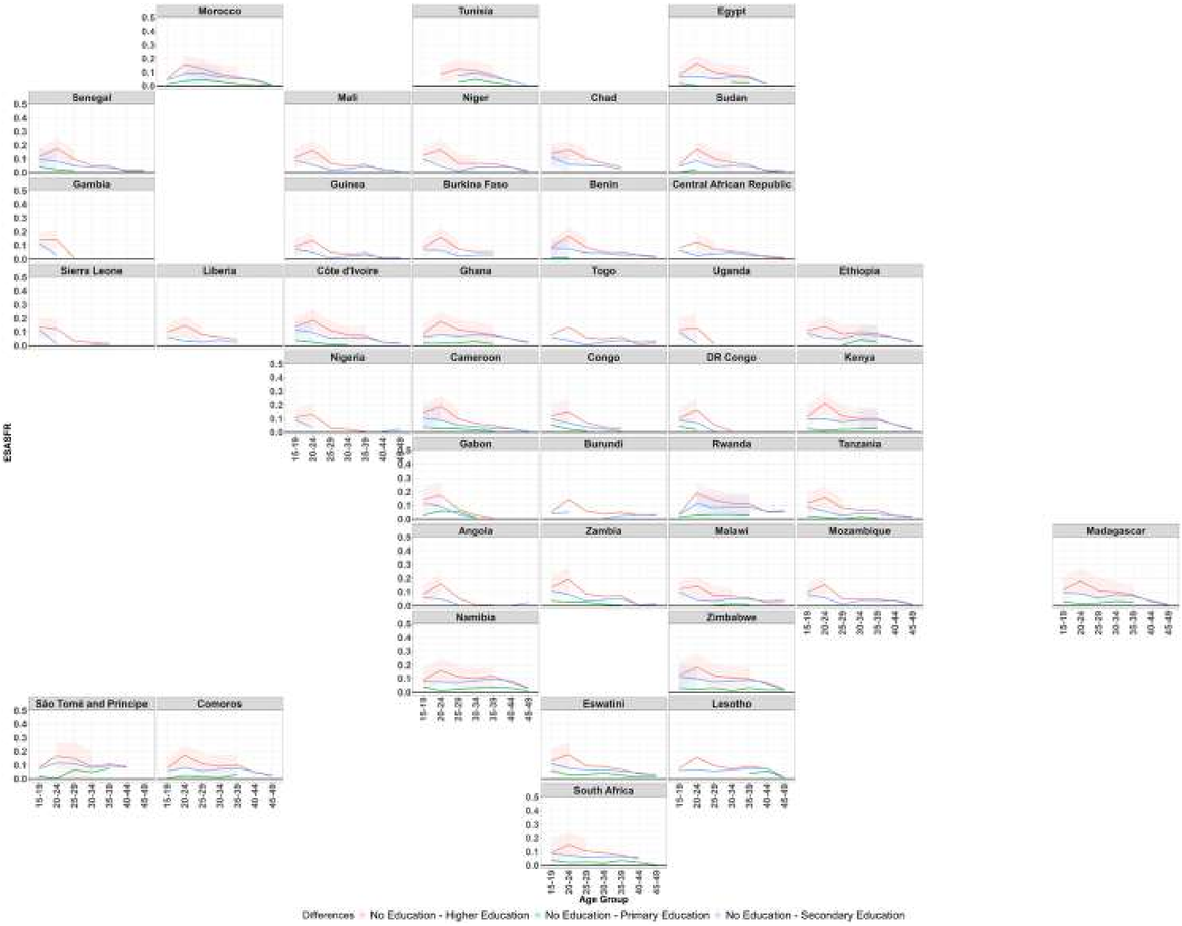


Figure C-3: Differences in education-specific, age-specific fertility rates, 1980–1985

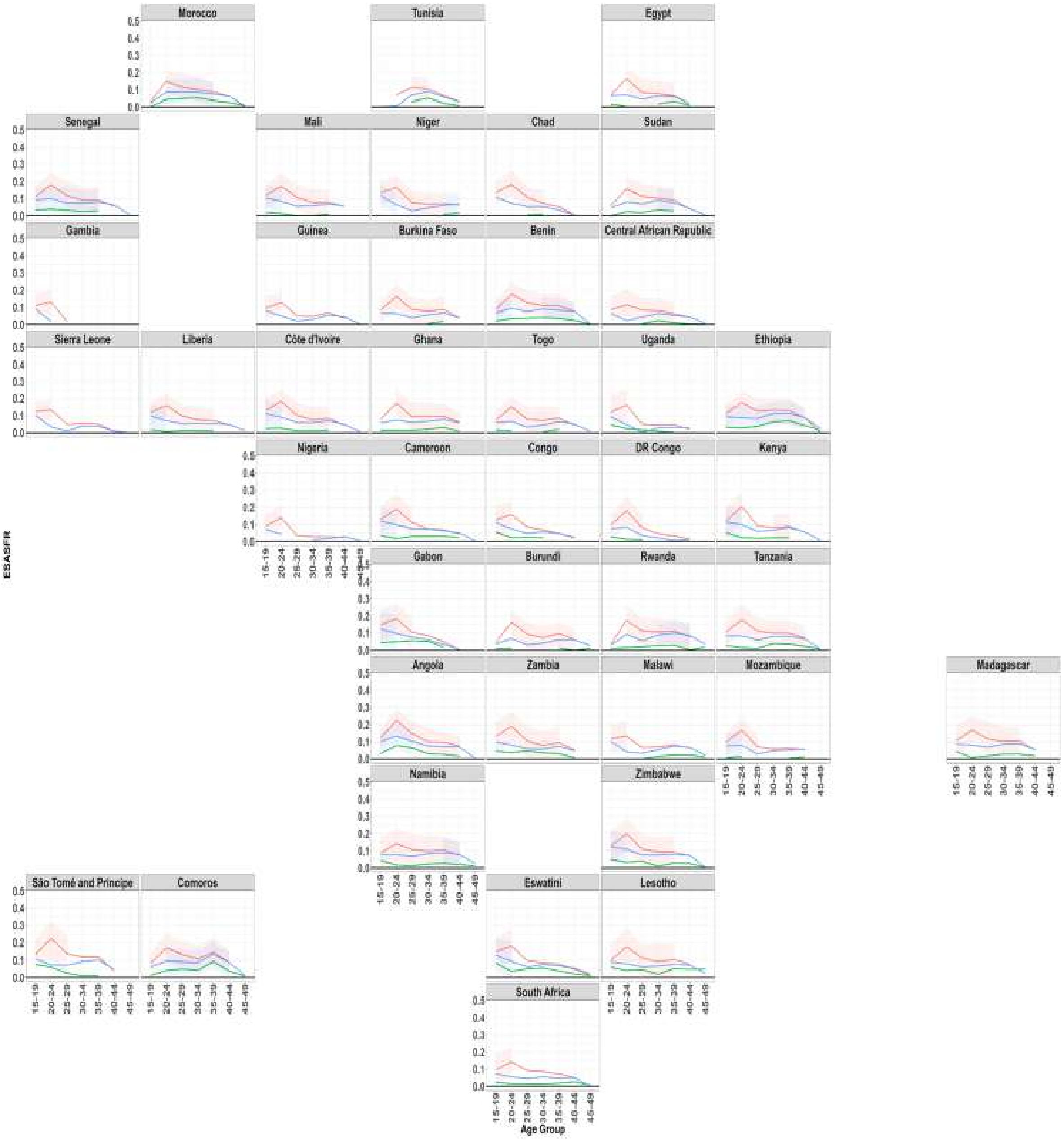


Figure C-4: Differences in education-specific, age-specific fertility rates, 1985–1990

Figure C-5: Differences in education-specific, age-specific fertility rates, 1990–1995

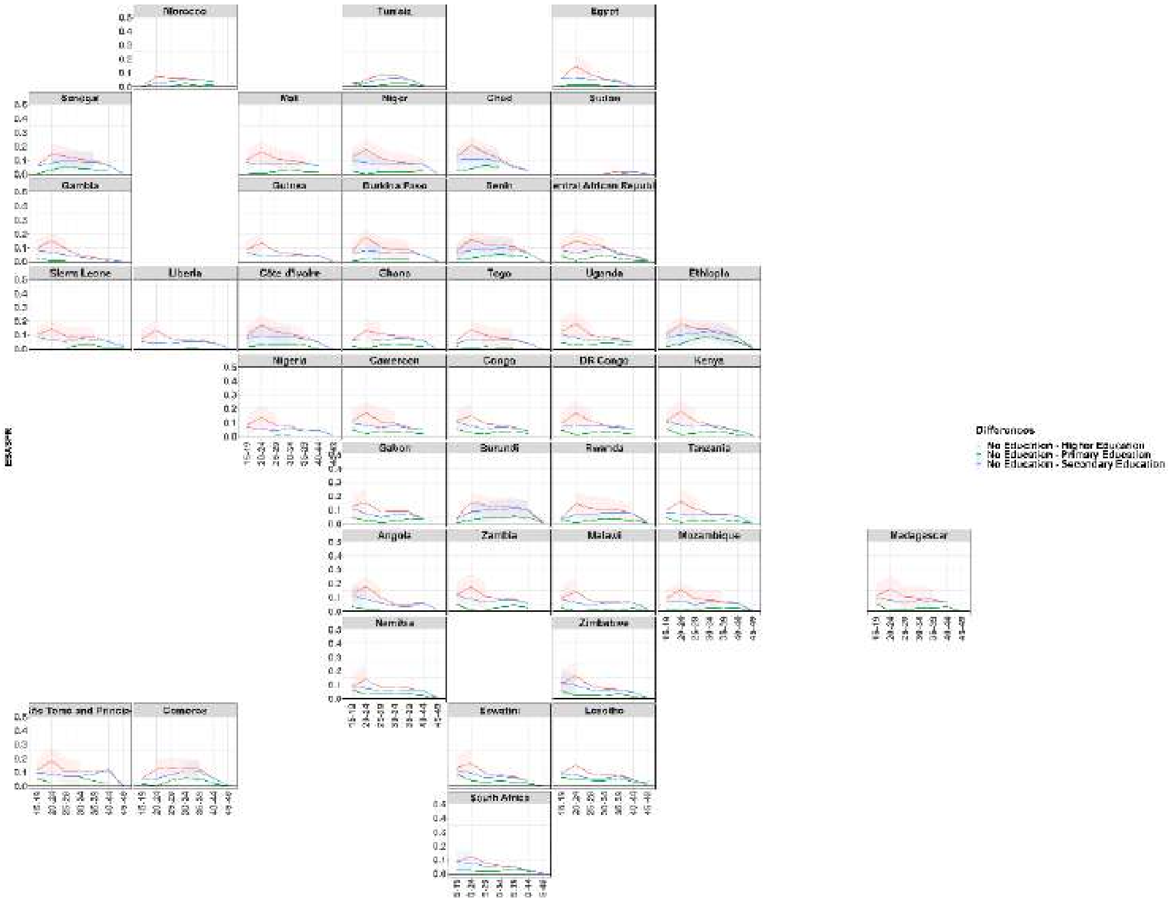


Figure C-6: Differences in education-specific, age-specific fertility rates, 1995–2000

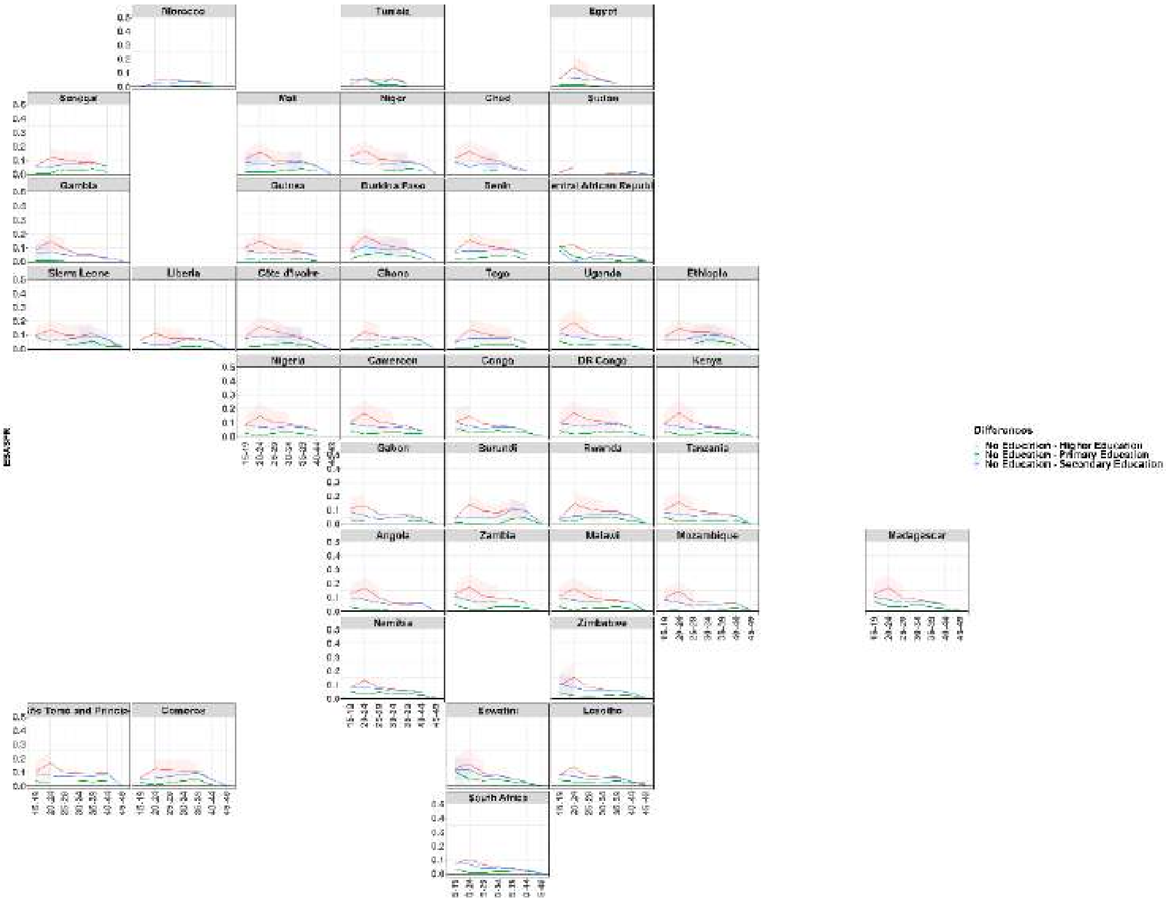


Figure C-7: Differences in education-specific, age-specific fertility rates, 2000–2005

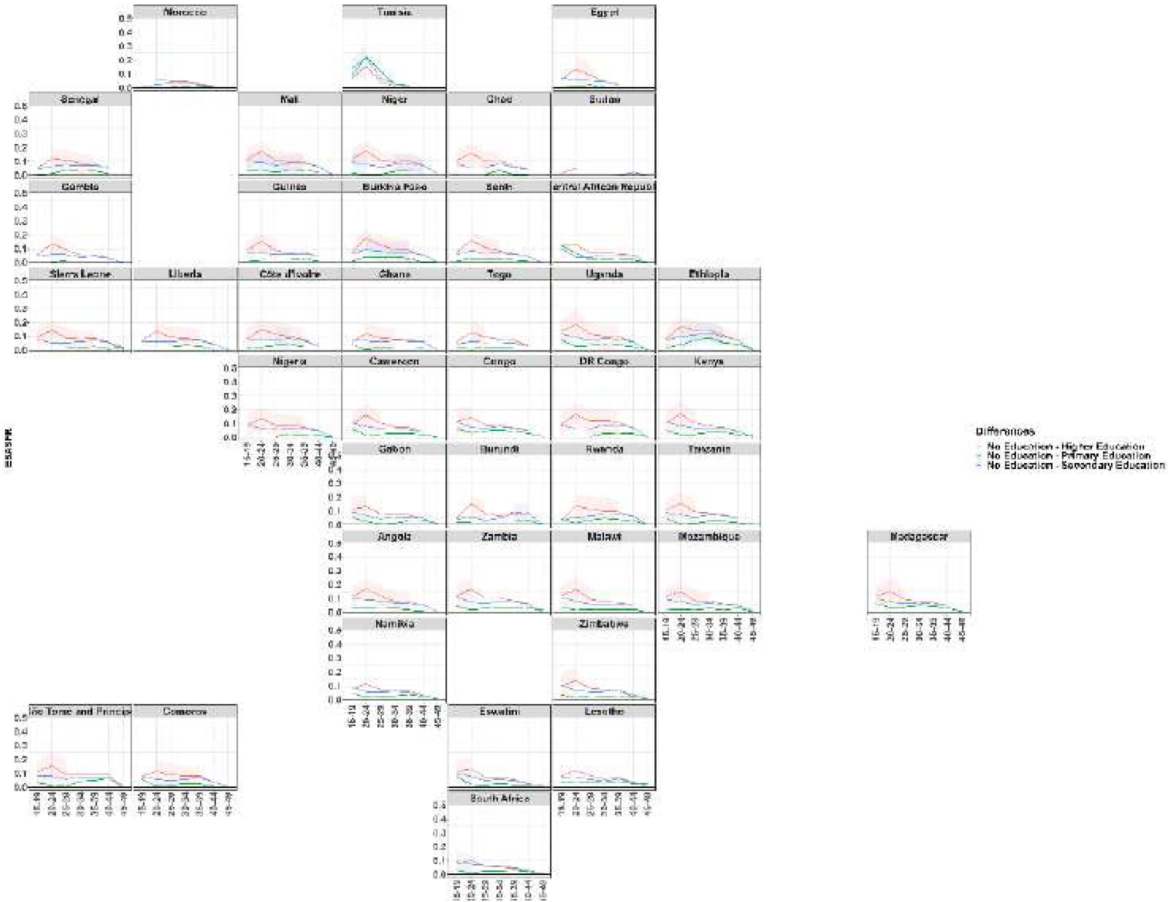


Figure C-8: Differences in education-specific, age-specific fertility rates, 2005–2010

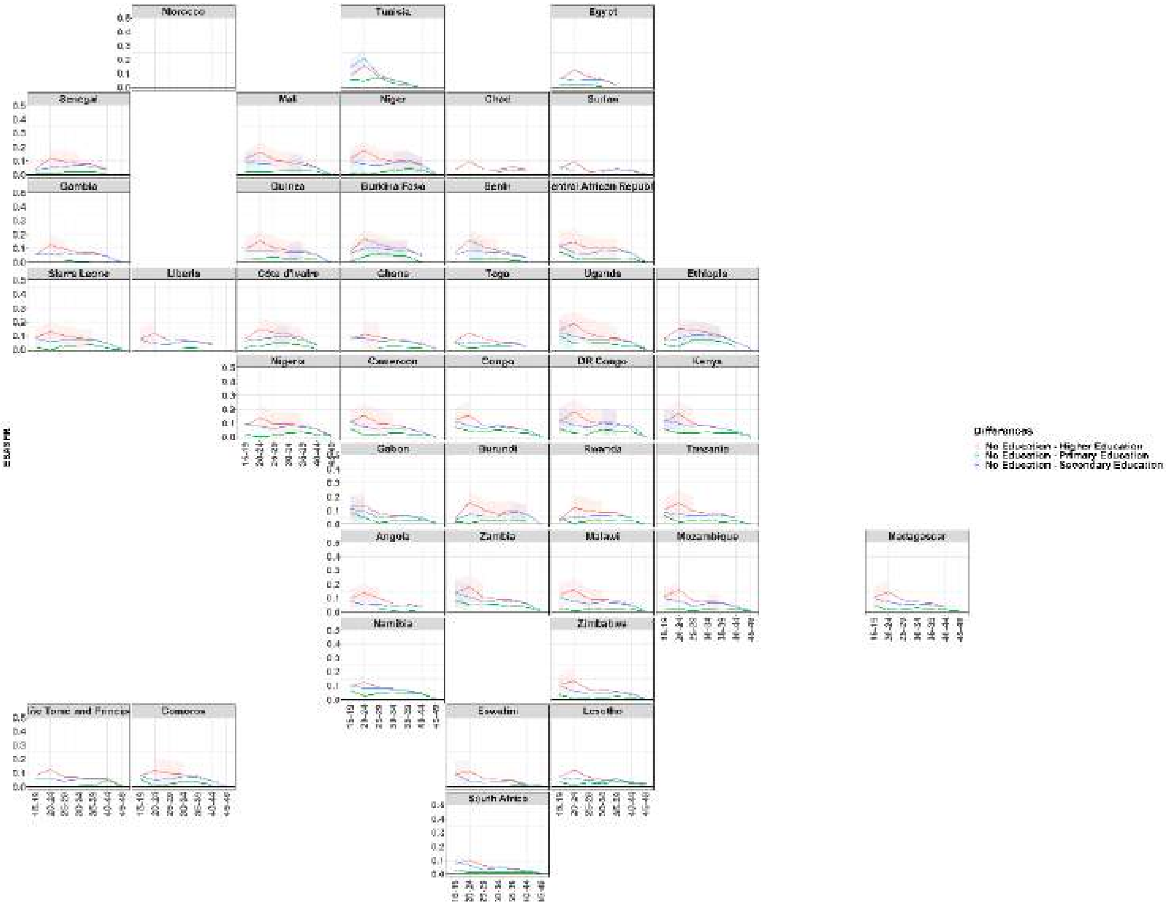


Figure C-9: Differences in education-specific, age-specific fertility rates, 2010–2015

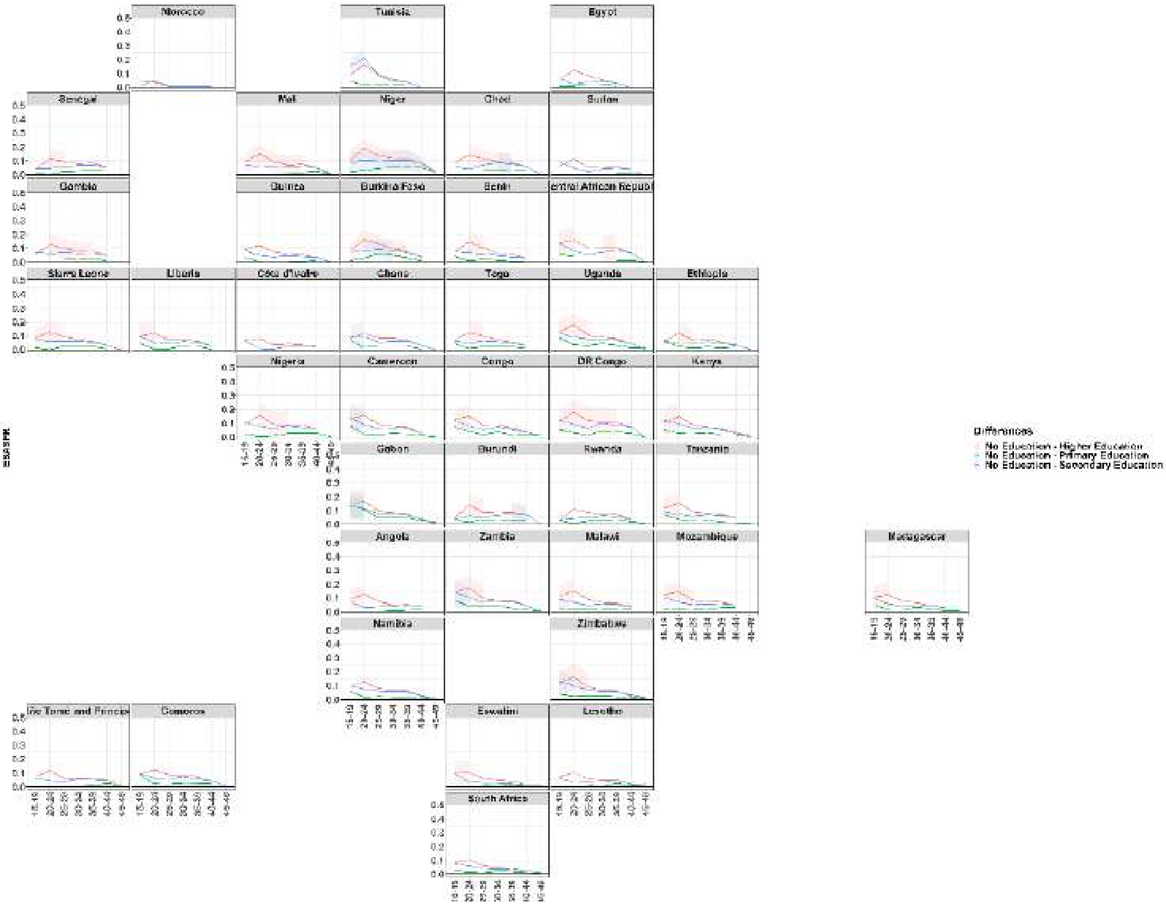
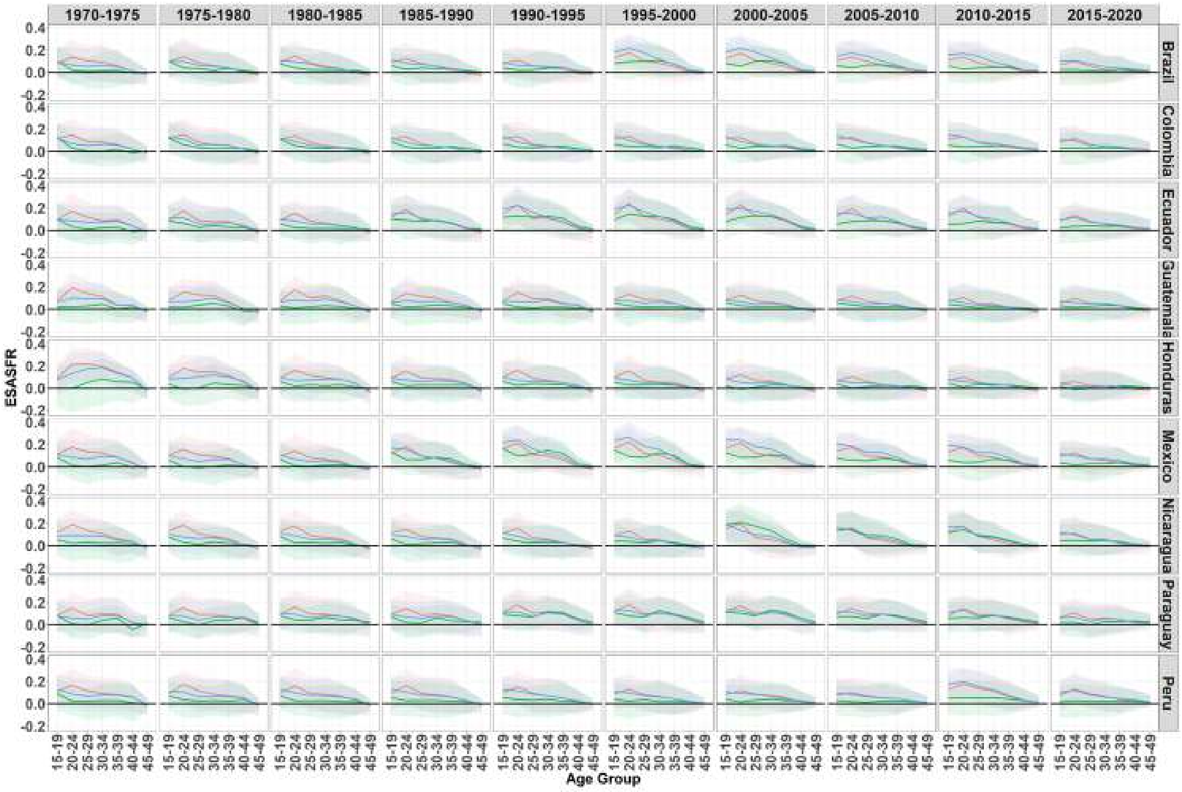


Figure C-10: Differences in education-specific, age-specific fertility rates, 2010–2015

Figure C-11: Differences in education-specific, age-specific fertility rates



Appendix D: List of items in supplementary material

Name	Description
cc_y_edu_all_paper_models.csv	UN-consistent ESTFR estimates by Yildiz et al. (2023)
Cleaned_DHS_LA.xlsx	DHS estimates from tfr2 module for Latin American countries
Cleaned_DHS_Africa.xlsx	DHS estimates from tfr2 module for African countries
Bayesian model Africa.R	R code for Bayesian fertility rates for African countries
Bayesian model Latin America.R	R code for Bayesian fertility rates for Latin American countries
Glm code.R	Glm code for initial inputs for Bayesian estimation
glm_predict_all.xlsx	Glm estimates serving as initial values
Validation EASFR Africa.R	Model validation code for EASFRs Africa
Validation EASFR Latin America.R	Model validation code for EASFRs Latin America
UN_datasets3.xlsx	UN estimates from WPP 2022
WIC_datasets.xlsx	Female population estimates by age and education level from WIC
Validation_easfr Africa.pdf	PDF file containing graphs of validation exercise for Africa
Validation_easfr Latin America.pdf	PDF file containing graphs of validation exercise for Latin America

Note: Education-specific fertility estimates can be accessed at https://zenodo.org/record/8182960 and https://github.com/AfuaD-B/A-Bayesian-model-for-the-reconstruction-of-education--and-age-specific-fertility-rates

2.2. Age at first birth, completed fertility, and literacy skills in sub-Saharan Africa

This manuscript was submitted to Revue Quetelet. The first submission was acknowledged on April 19, 2024, and has been resubmitted following its second round of review.

Authors: Afua Durowaa-Boateng and Univ. Prof. Dr. Éva Beaujouan.

Abstract: In the context of demographic change, education contributes to fertility delay and decline, although the effect is most pronounced at secondary and higher education levels. However, most research in sub-Saharan Africa shows that although fertility rates have declined among lower-educated women, it is mainly among women who have completed at least a secondary education that significantly lower fertility rates occur. In addition to this observation, reports suggest a substantial proportion of women completing primary education fail to acquire basic literacy skills, likely due to low educational quality in sub-Saharan Africa. We examine whether literacy skills, independent of education levels, may be related to fertility behaviour and outcome, particularly age at first birth and completed fertility. Using DHS data, we analyse whether literacy is associated with age at first birth and completed fertility for women born between 1940 and 1980 with different levels of education in 38 sub-Saharan African countries. Our results suggest that overall, literacy within education levels does not significantly alter the age at first birth on average; however, in countries with higher primary education literacy prevalence, a modest delay is observed. The magnitude of the difference is small, but literate women, whether they have no education or primary education, tend to have slightly fewer children than illiterate women, suggesting that while literacy contributes to fertility reduction, its effect is considerably smaller than the effects of higher levels of education.

Age at first birth, completed fertility, and literacy skills in sub-Saharan Africa

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DATA AVAILABILITY STATEMENT

DHS data are publicly available. The data is available for download after registration and can be found at: https://dhsprogram.com/data/available-datasets.cfm.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

Age at first birth, completed fertility, and literacy skills in sub-Saharan Africa

Abstract

While education contributes to delayed first births and reduced fertility, substantial disparities remain between women with primary and secondary education in sub-Saharan Africa. Many women who complete primary education in the region do not acquire basic literacy skills, likely due to limitations in education quality. Although school enrolment rates—particularly at the primary level—have increased, literacy rates have not risen as much. This gap raises the question of whether literacy acquisition, irrespective of formal education, influences fertility behaviour. Using Demographic and Health Survey (DHS) data, this study examines the impact of literacy skills, independent of education level, on two indicators of female cohort fertility: age at first birth and completed fertility, in 38 sub-Saharan African countries. Literacy does not significantly delay the age at first birth among women of a given education level. However, in countries where literacy among primary-educated women is widespread, a modest delay is observed, likely reflecting indirect social influences or diffusion processes rather than a direct effect of literacy. Additionally, literate women with no formal education tend to have fewer children than illiterate women with no education or only primary education. Nevertheless, the link between literacy and fertility is much weaker than that between higher educational attainment and fertility.

Keywords: Literacy, Sub-Saharan Africa, Education, Cohort fertility, Age at first birth.

INTRODUCTION

Researchers recognise education as a key driver of fertility decline, with higher educational levels associated with fewer children and delayed childbearing (e.g. DeCicca & Krashinsky 2017; Shapiro & Tenikue 2017; Sobotka et al. 2017; United Nations 2019). In sub-Saharan Africa, policies have promoted educational expansion—particularly at the primary level—to improve literacy, economic outcomes and gender equality. These efforts coincided with reductions in fertility rates, amid growing concerns about rapid population growth (Caldwell & Caldwell 1987; Grant 2015). While these policies have contributed to increased school enrolment (UNICEF 2023), their impact on skill acquisition, particularly in literacy and numeracy, remains inconsistent (Nishimura & Byamugisha 2011). The disconnect between expanding enrolment and limited skill acquisition underscores the importance of examining how literacy, an essential component of education, shapes fertility behaviour.

Educational attainment reflects both the length and quality of schooling; however, schooling alone does not guarantee literacy. In West and Central Africa, many women complete primary education without acquiring literacy skills (Smith-Greenaway 2015), revealing a significant disparity between formal attainment and actual competencies. Conversely, some women may acquire literacy outside the formal education system through literacy programmes (Maruatona 2008; Post 2016), potentially altering their fertility behaviour. Literacy, therefore, can develop both within and outside formal schooling, and may function as a distinct determinant of fertility.

Literacy tests, often used as proxies for education quality, measure an individual's ability to read and write. Altinok et al. (2018) argue that literacy reflects not only the duration of schooling but also the effectiveness of instruction. Stronger literacy skills may enhance women's economic empowerment and access to reproductive health information, thereby influencing fertility outcomes (Caldwell 1980). As a core component of human capital, literacy contributes to broader social and economic processes, from labour market participation to economic growth (Lutz et al. 2021; Reiter 2022).

Despite the central role of education in shaping fertility, the independent effect of literacy remains underexplored. Previous research in sub-Saharan Africa has shown that fertility tends to decline after secondary education (Bongaarts 2010; Obeng Gyimah 2003). However, more recent studies suggest that fertility is also beginning to decline among women with basic education, albeit to a lesser extent (Durowaa-Boateng et al. 2023; Schoumaker & Sánchez-Páez 2024). Still, wide disparities persist between women with basic and higher education (Schoumaker & Sánchez-Páez 2024). Similarly, the relationship between education and age at first birth varies across sub-Saharan Africa and over time (Grant 2015; Mahy & Gupta 2001). These patterns may reflect not only differences in education levels but also in literacy acquisition across groups.

This study investigates the relationship between literacy and fertility behaviour across sub-Saharan African countries. Adopting a cohort approach to reflect reproductive behaviour over the life course, it examines cohort-completed fertility and mean age at first birth. The analysis compares these indicators across literacy levels among women with no or primary education and across broader education levels. In light of the disparity in skill acquisition at the primary level, the study also explores fertility behaviour by years of schooling and literacy status among women with primary education.

BACKGROUND

Education influences female fertility through multiple mechanisms. One key pathway is the number of years spent in school, which often delays the transition into adulthood (Schultz 1997). Beyond delaying marriage and childbearing, formal education provides women with skills—especially literacy—that broaden their life opportunities and inform reproductive decision-making (LeVine et al. 2011; Parikh & Gupta 2001). Education is associated with various fertility-related factors, including contraceptive use, marriage and childbirth timing, postpartum behaviours and child survival rates (e.g. Bongaarts 2010; Ferré 2009; Kirk & Pillet 1998; Lutz et al. 2018). It also enhances employment opportunities and earnings potential, raising the opportunity cost of childbearing and, in turn, reducing fertility ambitions (May & Rotenberg 2020).

In much of sub-Saharan Africa, women's education remains a strong determinant of fertility preferences and behaviours (Bongaarts 2020; Schoumaker 2017). Yet, beyond individual educational levels, societal dynamics also shape reproductive behaviour. One key mechanism is the diffusion process, whereby less-educated women adopt the fertility behaviours of their more educated peers (Adhikari et al. 2024; Kravdal 2001). As more women attain higher levels of education, societal norms and expectations shift—often towards smaller families and delayed childbearing (Bongaarts 2010; Colleran et al. 2014). In contexts where many women are literate—even if they did not complete formal schooling—greater awareness of family planning options tends to emerge. This can lead to widespread behavioural change, with new norms diffused to lower-educated women (Kravdal 2001, 2002). Consequently, societies with a higher proportion of educated or literate women tend to exhibit lower fertility rates (Colleran et al. 2014; Kravdal 2012; Parikh & Gupta 2001).

The distinctive strength of literacy—whether acquired through formal education or not—lies in its capacity to improve comprehension and decision-making (Gee 1989; McMillan & O'Neil 2012). LeVine et al. (2011) showed that mothers who could recognise and understand words in health messages, whether in media or print, had better child health outcomes and lower child mortality, which can ultimately influence completed fertility. Literacy also supports the ability to understand contraception and family planning information, thereby enabling women to regulate fertility more effectively (Bongaarts 2010).

While Universal Primary Education (UPE) and Education for All (EFA) policies significantly increased school enrolment (UNICEF 2023), completion rates remain low. Many students face challenges that prevent them from finishing primary education, including resource shortages, repetition and the limited enforcement of compulsory education (Chimombo 2005; Lewin 2009). The rapid expansion of education systems has often outpaced infrastructure and staffing, contributing to poor teaching quality in government-owned or funded (public) schools (Bold et al. 2017; Heneveld & Craig 1996).

Despite the provision of free public education, private primary schools are widespread across sub-Saharan Africa (Uwakwe et al. 2008). Private primary schools usually have higher enrolment and perform better than government-funded schools—particularly in numeracy and literacy—due to lower teacher–student ratio, greater teacher commitment and improved facilities (Romuald 2023;

Tooley & Dixon 2005).

The resulting dual system of private and public education reinforces disparities in skill acquisition at the same educational level (Cheema 2024; Kouamo 2024). While net enrolment rates increased from 60.2% to about 75% from 2000 to 2009 (Ritchie et al. 2023), this did not translate into equivalent gains in literacy. Literacy among young women improved only modestly, from 57% in 2000 to 60.9% in 2010 (Roser & Ortiz-Ospina 2018). This modest rise may be partly explained by literacy statistics capturing a broader population, including older cohorts who are unlikely to benefit from recent educational reforms. Among school-age children, challenges—such as teacher shortages and the recruitment of untrained personnel—continue to affect learning outcomes (Somerset 2009).

Based mostly on Caldwell's (1980) thesis linking mass schooling and fertility decline, universal primary education was expected to reduce fertility (Lloyd et al. 2000). However, empirical evidence has been mixed. For instance, Grant (2015) found that education expansion in Malawi did not significantly delay age at first birth, although it did reduce ideal family sizes, potentially reducing completed fertility (Behrman 2015). Grant (2015) also observed a decline in education quality during this expansion, suggesting that dropout rates and poor schooling environments may limit the fertility-related benefits of UPE. These findings indicate that both education and literacy—especially at the primary level—can have varying effects on age at first birth and completed fertility, depending on quality and context.

Sub-Saharan Africa has a wide variety of cultural and institutional settings. Fertility behaviours are influenced not only by education and literacy but also by broader cultural norms, such as attitudes toward polygamy (Cleland et al. 1994; Hayase & Liaw 1997). West and Central African countries including Mali, Niger, Nigeria, Chad and the Central African Republic, where polygamy is more prevalent, tend to report higher total fertility rates and lower ages at first birth. In contrast, countries in Southern Africa, such as Namibia and South Africa, where polygamy is less common, exhibit lower total fertility rates (Fenske 2015; Rossi 2019; Schoumaker 2017; Tabutin et al. 2004; United Nations Population Division n.d.). This diversity highlights the need to examine fertility outcomes within diverse country contexts.

Finally, the timing of completion of education appears to be a key factor in entering parenthood (Adu Boahen & Yamauchi 2018; Kim 2023; Neels & De Wachter 2010; Neels et al. 2017; Ní Bhrolcháin & Beaujouan 2012). Notably, the impact of education, years of schooling, and literacy on female fertility varies, as demonstrated in the case of Malawi's education policies. Therefore, when studying the role of literacy skills in shaping age at first birth and completed fertility at the primary level, it is important to consider how years of schooling, which reflects women's school progression, may influence the relationship between literacy and fertility outcomes.

The main research question (RQ) we aim to answer is: At a given level of education, is literacy

associated with age at first birth and completed fertility in sub-Saharan African countries?
We summarise the sub-research questions, which supplement our main research question, as follows:

RQ1: Among women with no education and primary education, do literate women have fewer children and at a later age than non-literate women?

RQ2: Do literate women with primary education have the same mean age at first birth and completed fertility as secondary-educated women?

RQ3: Do we observe different or similar patterns in these relationships depending on the prevalence of literacy among women with a primary education in each country?

RQ4: Do years spent in schooling at the primary education level reduce or change the effects of literacy?

DATA

This study uses data from the Demographic and Health Surveys (DHS), a series of nationally representative surveys conducted in more than 90 low- and middle-income countries (Rutstein & Rojas 2006). The DHS is the most comprehensive and reliable source of demographic and educational data in these settings. We use data from 38 sub-Saharan African countries, spanning survey waves conducted between 1986 and 2019 (see Appendix A, Table A1 for the full list). To analyse fertility outcomes, we construct two datasets. For age at first birth, we use the Birth Recode (BR) file, which links child-level data to maternal characteristics. We include only firstborn children born before their mothers turned 40, and whose mothers were aged 40–50 at the time of the survey. This captures typical fertility patterns, as fewer than 1% of first births occur after age 40 in the region (Dunlop et al. 2018). For completed fertility, we use the Individual Recode (IR) file, selecting women aged 40–50 and using the total number of children ever born as our outcome.

Explanatory variables:

In our study, we use the following variables:

Level of education at the time of the survey. The DHS categorises education levels as no education, primary education, secondary education, and higher education. This variable captures the highest level of education reported by respondents at the time of the survey. In the analysis, women with higher education are retained despite their small sample size because they represent a socially and demographically distinct group of women, irrespective of the age at first birth (Mahy & Gupta 2001). Furthermore, while higher education may (rarely) be attained post-childbearing, we retain it as a distinct category to reflect different fertility and literacy profiles.

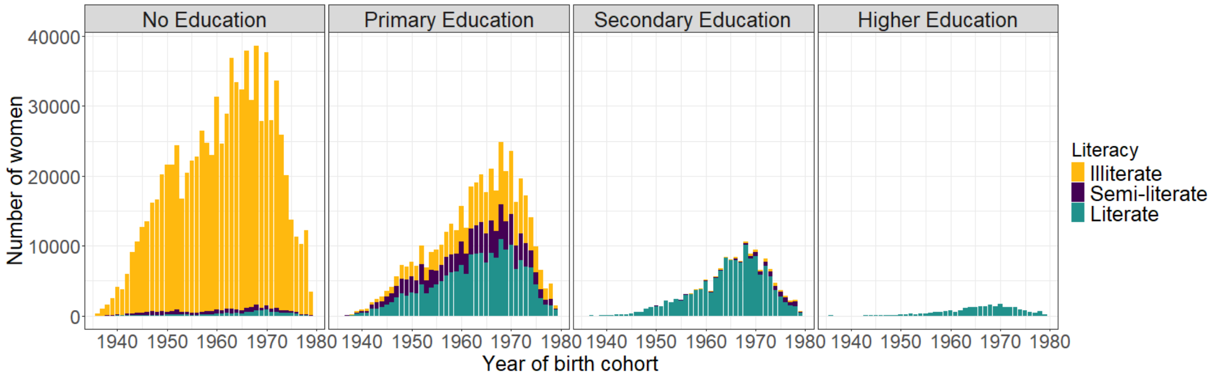
Literacy skills at the time of the survey. The DHS assesses literacy skills using a card with four simple sentences, presented in a language the respondent is likely to understand—often an official or local language—to ensure broad linguistic coverage[1] (MEASURE DHS 2008). This method is widely considered reliable and valid for cross-country comparisons (MEASURE DHS 2008; Oye et al. 2016). We categorise women who could read all sentences as literate, those who could read some sentences as semi-literate, and those unable to read as illiterate. Since the literacy test was conducted at the time of the survey rather than at first birth, we assume minimal skill attrition. This assumption aligns with the empirical findings Barrett and Riddell (2016), who demonstrated that literacy skills generally remain stable for people in their 20s to 40s. Literacy tests for women with secondary education were only introduced in later survey rounds, starting with the seventh DHS phase. Given our longer-term approach, we do not use the information available in the latest surveys on literacy among women with secondary education: assessing literacy only among less-educated women is sufficient for our analysis.

The *education and literacy skill* composite variable combines respondents' education level and literacy status. Following Pritchett and Sandefur (2020), we construct this measure exclusively for women with no or primary education. The composite variable produced eight categories: no education and literate, no education and semi-literate, no education and illiterate, primary education and literate, primary education and semi-literate, primary education and illiterate, secondary education, and higher education. Secondary and higher education groups are included in our models to enable meaningful comparisons with lower-educated groups.

Year of birth of the woman represents her birth cohort, allowing us to control for changes in first birth timing and completed fertility over time. A cohort approach is adequate as cohort measures reflect actual reproductive behaviour, avoiding the distortions that arise from tempo shifts in period-based measures (Myrskylä et al. 2013). Figure 1 presents the weighted number of women in the final sample by birth cohort, literacy skills, and education level.

[1] It is unclear whether the literacy test was conducted in the official language of the respondent's country or in a local language used in health services. This distinction is important because literacy in different languages may influence access to family planning information.

Figure 1: Composition of the sample by birth cohort, literacy and education level, women aged above 40 at survey time.



Most women in our sample from sub-Saharan Africa had no formal education (Figure 1). The majority of these women are illiterate. For women with primary education, a substantial proportion are either illiterate or semi-literate. We show the literacy level of women with secondary education for information. As seen, only the latest birth cohorts have this information, but most of them are literate. Women with higher education represent a small fraction of the sample.

***Outcome variables*:**

Our first outcome variable is *age at first birth*. The DHS calculates this using the mother's reported date of birth and the birthdate of their first child. A well-documented data quality issue in DHS surveys is age heaping, where respondents round birth years to the nearest zero or five, leading to systematic misreporting (Al Zalak & Goujon 2017; Schoumaker 2011). To minimise the impact of heaping, we implement statistical adjustments in our analysis (details in the Method section).
Our second outcome variable is *number of children ever born*. The DHS derives this variable from full birth histories, including all sons and daughters—living, deceased, or living elsewhere. It uses multiple verification steps to cross-check responses and resolve inconsistencies during the interview process ("The DHS program" n.d.; MEASURE DHS 2008).

Weighting

We apply DHS survey weights (v005, but rescaled, that is, v005/1,000,000) using the "svydesign" and "svytable" functions from the R package survey (Lumley 2020) to ensure representativeness. These weights account for sampling design and non-response, ensuring that our estimates reflect national populations. We do not apply additional weights for national population sizes, in order to preserve survey-based comparability across countries. We then generate weighted frequency tables, capturing the total number of children ever born and age at first birth, disaggregated by the variables of interest: literacy status, educational attainment, birth cohort, and survey year. This process is applied separately to each country and survey wave listed in Appendix Table A1. Finally, we combine data from all survey waves and countries to construct a unified dataset for analysis. Weighted means were calculated using the unified data grouped by year of birth, education level, literacy status, survey year, and, where necessary, years of schooling. Although the survey year was not modelled, it was retained during aggregation to avoid issues that may arise from pooling across DHS waves. We excluded cases from all datasets where respondents, despite reporting higher education, were classified as illiterate or semi-literate, as such discrepancies likely resulted from misreporting. The modelling excludes groups with a single observation and weighted sample size below two to reduce instability. The final sample sizes for both data sets are presented in Appendix A, Table A2.

METHOD

Modelling approach

We employ generalised additive models (GAMs) to analyse fertility outcomes due to their flexible and interpretable approach to modelling non-linear trends in demographic data (Ellison et al. 2022). GAMs are particularly well-suited to this study, which examines both completed fertility (a count outcome) and mean age at first birth (a continuous variable), as they allow for smooth, data-driven relationships without imposing rigid parametric forms. This flexibility is useful, as reproductive behaviours across cohorts are unlikely to follow simple linear or quadratic trajectories (see Appendix B, Figure B1 for the non-linear relationship of mean age at first birth by cohort).

Traditional parametric models, such as Poisson regression, which is typically used for count data, require predefined functional relationships. These models may overlook meaningful variations across birth cohorts, education levels, or national contexts, particularly in response to changes in social norms or policies. Although spline terms can be incorporated into Poisson models, GAMs offer a more integrated and interpretable framework for capturing these complexities. In our specifications, country-specific smoothing terms, s(Year of birth)$_{country}$ allow cohort effects to vary flexibly across countries, capturing the heterogeneity of fertility transitions. These smoothing functions fit continuous curves to the data and reveal non-linear patterns that standard parametric models may obscure (Wood 2017).

Model specifications

We use a multi-country model with country-specific fixed effects to account for contextual differences. To address RQ1 and RQ2, we estimate separate GAMs for age at first birth and completed fertility. The first model estimates the expected age at first birth as a function of education, literacy, and country-specific factors.

$$
\begin{aligned}
E(\text{age at first birth}) &= \beta_0 + \beta_i \cdot \text{Education and literacy skill}_i + \beta_j \cdot \text{Country}_j \\
&+ \sum_p \beta_p(\text{s}(\text{Year of birth})_{\text{country}}).
\end{aligned} \tag{1}
$$

Similarly, the second model estimates the total number of children ever born, using the same set of predictors:

$$
\begin{aligned}
E(\text{number of children ever born}) &= \beta_0 + \beta_i \cdot \text{Education and literacy skill}_i + \beta_j \cdot \text{Country}_j \\
&+ \sum_p \beta_p(\text{s}(\text{Year of birth})_{\text{country}}).
\end{aligned} \tag{2}
$$

These models allow us to analyse variations in the mean age at first birth and completed fertility across different education and literacy levels. For clarity in presentation, we use a categorical variable approach. We use a composite education and literacy variable to capture the joint effect of both factors while reducing multicollinearity and the risk of over-fitting inherent in interaction models. In the presentation of all the models' results, the composite variable "Primary Education and Literate" remains the reference category. An alternative interaction model (Appendix D) confirms our main results, demonstrating that the level of education remains the dominant predictor of fertility outcomes. Our models assume a normal distribution for the link function[2]. Weighted samples, N are incorporated as weights, as permitted by the "bam" function.

Incorporating literacy prevalence at the country level

To address RQ3 and its hypotheses, we examine the importance of literacy prevalence at the country level. We classify countries based on primary education literacy prevalence, using a 60% threshold—consistent with reported literacy rates in sub-Saharan Africa (Roser & Ortiz-Ospina 2018). This threshold reflects the regional average and distinguishes between settings where primary education is more or less likely to result in literacy. Countries are categorised as having widespread literacy (≥60% of women with a primary education are literate) or limited literacy (<60%). We estimate separate models for high- and low-literacy-prevalence countries to determine whether the relationship between fertility and literacy among low-educated women differs depending on literacy prevalence. A three-way interaction was considered but not implemented because of concerns about model overfitting and difficulty in interpreting higher-order interactions.

The GAMs for this analysis are specified as follows:

[2] We use the R package "mgcv" and function "bam" "bam" by Wood (2017). We choose a normal distribution due to the continuous nature of our variables, particularly age at first birth. Furthermore, completed fertility among the age groups we study approximates a normal distribution, making Gaussian GAMs a more suitable choice. Poisson models, by contrast, may suffer from overdispersion, leading to biased estimates of fertility variability. Finally, Gaussian GAMs are computationally stable, interpretable, and effective for smoothing trends.

$$E(\text{age at first birth}) = \beta_0 + \beta_i \cdot \text{Education and literacy skill}_i + \beta_j \cdot \text{Country}_{\text{literacy prevalence group}\,j} + \sum_p \beta_p(\text{s}(\text{Year of birth})_{\text{country}_{\text{literacy prevalence group}}}). \tag{3}$$

$$E(\text{number of children ever born}) = \beta_0 + \beta_i \cdot \text{Education and literacy skill}_i + \beta_j \cdot \text{Country}_{\text{literacy prevalence group}\,j} + \sum_p \beta_p(\text{s}(\text{Year of birth})_{\text{country}_{\text{literacy prevalence group}}}). \tag{4}$$

Focusing on primary-educated women

To assess how schooling duration influences literacy and fertility, we further analyse women with primary education. Prior research suggests that some women remain functionally illiterate even after five years of schooling (Smith-Greenaway 2015). Since surveys conducted after 2000 provide consistent data on years of schooling, we restrict our analysis to this period to mitigate bias[3]. Our models for primary-educated women include years spent in school as a predictor:

$$E(\text{age at first birth}) = \beta_0 + \beta_i \cdot \text{Education and literacy skill}_i + \beta_k \cdot \text{Years in school}_k + \beta_j \cdot \text{Country}_j + \sum_p \beta_p(\text{s}(\text{Year of birth})_{\text{country}}). \tag{5}$$

$$E(\text{number of children ever born}) = \beta_0 + \beta_i \cdot \text{Education and literacy skill}_i + \beta_k \cdot \text{Years in school}_k + \beta_j \cdot \text{Country}_j + \sum_p \beta_p(\text{s}(\text{Year of birth})_{\text{country}}). \tag{6}$$

Our models yield expected mean values for age at first birth and total number of children in all categories of the variables. We do not include control variables such as employment and marital status in the models for two reasons. First, these statuses fluctuate throughout life and we know them only at the time of survey, making it difficult to isolate their pre-childbearing effect. Second, while excluding these variables limits causal interpretation, our focus is on uncovering broad demographic patterns rather than causal mechanisms.

RESULTS

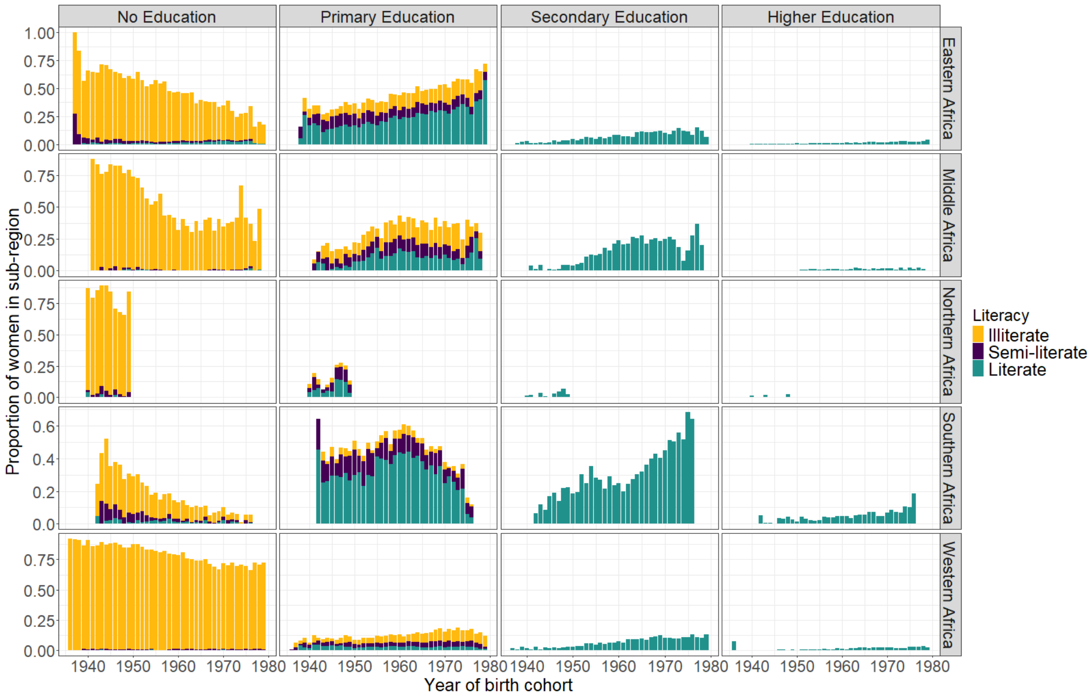
Level of education and literacy by sub-region

Figure 2 presents the distribution of respondents' education and literacy levels across sub-regions and birth cohorts. The proportion of women with no formal education has steadily declined

[3] We excluded all values above 90 to remove any variation of the missing code (99).

across all regions, with primary education becoming more prevalent and a notable increase in secondary education in Southern Africa.

Figure 2: Level of education and literacy, distribution by birth cohort and sub-region, among women above age 40 at the time of survey



Illiteracy rates have decreased across all sub-regions, but disparities remain. Middle, Eastern, and Western Africa continue to have significantly higher proportions of illiterate women—especially among those with no formal education—compared to Southern Africa, where illiterate women with primary education are less common. Additionally, Southern Africa consistently exhibits higher literacy rates across all education levels, while Western Africa has the lowest literacy rates. In Sudan (Northern Africa)[4], the majority of women without formal education are illiterate. Across all sub-regions and birth cohorts, women with higher education remain a small minority, likely reflecting persistent disparities in educational access and quality.

Mean age at first birth and completed fertility by education and literacy skill

Table 1 examines the relationship between education, literacy, and fertility outcomes, controlling for other factors (Appendix C1). The composite education and literacy skill variable is used to assess whether literacy affects fertility timing and completed fertility within educational groups. Among women with no or primary education, being illiterate is associated with higher completed fertility. Furthermore, among literate women, those with no formal education and those with

[4] Sudan is included as sub-Saharan Africa in the DHS database but classified under the UN as Northern Africa (United Nations Statistics Division n.d.).

primary education show similar patterns in both the mean age at first births and completed fertility; however, the wider confidence intervals suggest that these comparisons should be interpreted with caution.

Table 1: Coefficients and 95% confidence intervals for the estimated mean age at first birth and total number of children.

Parameter	Mean age at first birth (Equation 1)	Mean number of children (Equation 2)
Intercept	23.03 [15.53; 30.53]*	6.11 [5.80; 6.42]*
No Education and Illiterate	−0.17 [−0.24; −0.11]*	0.67 [0.62; 0.72]*
No Education and Semi-literate	−0.22 [−0.41; −0.03]*	0.30 [0.16; 0.44]*
No Education and Literate	0.11 [−0.13; 0.34]	0.01 [−0.16; 0.18]
Primary Education and Illiterate	−0.06 [−0.15; 0.02]	0.39 [0.33; 0.45]*
Primary Education and Semi-literate	0.00 [−0.09; 0.10]	0.05 [−0.01; 0.12]
Primary Education and Literate	RC	RC
Secondary Education	1.41 [1.33; 1.50]*	−1.33 [−1.39; −1.28]*
Higher Education	4.01 [3.85; 4.17]*	−2.57 [−2.65; −2.48]*

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$; Reference Category (RC).
The full model is available in Appendix C1; we present here the intercept, the coefficients of the variable that combines education and literacy, and the coefficient of the groups with secondary and with higher education.

However, regardless of literacy level, primary-educated women tend to have lower mean ages at first birth and higher completed fertility than women with secondary education. These results suggest that literacy may be associated with fertility outcomes, but does not offset the impact of education level: the strongest fertility-limiting effects occur among women with secondary and higher education rather than among literate women with no or primary education.

The role of literacy prevalence in primary education for fertility outcomes

Table 2 presents separate models of age at first birth for countries with “widespread” vs. “limited” literacy prevalence among women with primary education, as described in the Method section. In countries with widespread literacy, illiterate women tend to have earlier ages at first birth compared to their literate counterparts. In contrast, in countries with limited primary-level literacy, literacy status has no significant effect on mean age at first birth, suggesting that other structural factors, such as economic conditions or cultural norms, may play a more decisive role. Across all contexts, women with secondary education experience later ages at first birth than those with only primary education, regardless of literacy prevalence. Overall, the relationship between literacy and the age at which a woman has her first child is modest and context-dependent.

Table 2: Coefficients and 95% confidence intervals for the estimated average age at first birth from the selected GAM for countries with limited and widespread literacy prevalence in primary education.

Parameter	Widespread	Limited
Intercept	21.99 [20.62; 23.35]*	22.83 [15.48; 30.19]*
No Education and Illiterate	−0.57 [−0.67; −0.47]*	−0.01 [−0.10; 0.08]
No Education and Semi-literate	−0.15 [−0.43; 0.13]	−0.22 [−0.46; 0.03]
No Education and Literate	0.19 [−0.08; 0.45]	−0.21 [−0.60; 0.18]
Primary Education and Illiterate	−0.40 [−0.56; −0.23]*	0.08 [−0.03; 0.18]
Primary Education and Semi-literate	−0.22 [−0.37; −0.08]*	0.15 [0.03; 0.27]*
Primary Education and Literate	RC	RC
Secondary Education	1.57 [1.43; 1.70]*	1.46 [1.35; 1.57]*
Higher Education	4.36 [4.05; 4.67]*	4.03 [3.84; 4.23]*

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$; Reference Category (RC).
The full model is available in Appendix C2; we presented here the intercept, the coefficients of the variable that combines education and literacy, and the coefficient of the groups with secondary and higher education for areas with limited and widespread literacy prevalence within primary education.

Table 3 presents the results for completed fertility by country's literacy prevalence. We find that literate women tend to have fewer children than illiterate women in both country groups. Women with secondary education have consistently lower fertility across all contexts. Literacy alone is insufficient to achieve fertility patterns similar to those of women with secondary education, but among less educated women, those who are literate are also those who have fewer children. These results suggest that while literacy is associated with lower fertility within education groups, secondary education remains the strongest factor in reducing fertility.

Table 3: Coefficients and 95% confidence intervals for completed fertility in countries with widespread and limited literacy prevalence in primary education.

Parameter	Widespread	Limited
Intercept	5.68 [4.69; 6.68]*	6.05 [5.74; 6.36]*
No Education and Illiterate	0.44 [0.36; 0.51]*	0.76 [0.70; 0.83]*
No Education and Semi-literate	0.22 [0.02; 0.43]*	0.36 [0.19; 0.54]*
No Education and Literate	−0.01 [−0.21; 0.18]	−0.06 [−0.33; 0.22]
Primary Education and Illiterate	0.25 [0.13; 0.38]*	0.47 [0.40; 0.54]*
Primary Education and Semi-literate	0.11 [0.01; 0.22]*	0.07 [−0.01; 0.15]
Primary Education and Literate	RC	RC
Secondary Education	−1.39 [−1.48; −1.30]*	−1.26 [−1.33; −1.19]*
Higher Education	−2.37 [−2.53; −2.22]*	−2.57 [−2.68; −2.46]*

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$; Reference Category (RC). The full model is available in Appendix C3; we presented here the intercept, the coefficients of the variable that combines education and literacy, and the coefficient of the groups with secondary and higher education for areas with limited and widespread literacy prevalence within primary education.

Primary education, years of schooling, and fertility outcomes

To answer our last question (RQ 4), we focus only on primary-educated women in surveys conducted after 2000, where data on years of schooling are available.

Table 4 presents the results from models 5 and 6 which examine whether the relationship between literacy and fertility outcomes remains after controlling for school duration. The models that do not control for length of schooling provide a benchmark against which we can assess whether the observed association between literacy and fertility outcomes is explained by variation in time spent at school.

The results show that longer schooling is associated with delays in first births and a reduction in completed fertility. Once school duration is accounted for, the effect of literacy on both fertility indicators weakens. Years of schooling account for much of the variation in fertility timing, reducing the stand-alone effect of literacy. Once controlling for years of schooling, a modest delay in age at first birth is observed among illiterate women with primary education compared to their literate counterparts. This pattern may reflect grade repetition or delayed school progression rather than a direct influence of literacy. Overall, these results emphasise that years of schooling—not just literacy—are crucial in shaping fertility timing and outcomes.

Table 4: Coefficients and 95% confidence intervals for age at first birth and completed fertility only for primary education.

Parameter	Mean age at first birth (Equation 5)	Mean age at first birth	Mean number of children (Equation 6)	Mean number of children
Intercept	21.38 [19.03; 23.74]*	21.41 [19.12; 23.70]*	6.35 [5.42; 7.28]*	6.27 [5.28; 7.26]*
Primary Education and Illiterate	0.21 [0.11; 0.30]*	−0.06 [−0.14; 0.02]	0.19 [0.12; 0.27]*	0.47 [0.41; 0.54]*
Primary Education and Semi-literate	0.18 [0.09; 0.28]*	0.05 [−0.04; 0.14]	−0.05 [−0.12; 0.02]	0.08 [0.01; 0.15]*
Primary Education and Literate	RC	RC	RC	RC
Years of schooling: 0	−0.21 [−0.50; 0.07]		0.11 [−0.11; 0.32]	
Years of schooling: 1	−0.31 [−0.47; −0.14]*		0.34 [0.22; 0.47]*	
Years of schooling: 2	−0.25 [−0.39; −0.11]*		0.26 [0.15; 0.37]*	
Years of schooling: 3	−0.20 [−0.32; −0.07]*		0.25 [0.15; 0.34]*	
Years of schooling: 4	−0.18 [−0.30; −0.05]*		0.13 [0.04; 0.23]*	
Years of schooling: 5	RC		RC	
Years of schooling: 6	0.04 [−0.08; 0.15]		−0.13 [−0.22; −0.05]*	
Years of schooling: 7	0.47 [0.33; 0.61]*		−0.43 [−0.53; −0.33]*	
Years of schooling: 8	0.93 [0.73; 1.14]*		−0.76 [−0.90; −0.61]*	
Years of schooling: 9	1.62 [0.27; 2.97]*		−1.34 [−2.24; −0.44]*	
Years of schooling: 10+	3.39 [1.26; 5.53]*		−2.22 [−3.41; −1.02]*	

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$; Reference Category (RC). The full model is available in Appendix C4; we presented here the intercept, the coefficients of the variable that combines education and literacy only for primary education, and the coefficient of the years spent in schooling.

DISCUSSION AND CONCLUSION

This study examines the role of literacy and education in shaping mean age at first birth and completed fertility in sub-Saharan Africa. The analyses consistently highlight that education level is the strongest predictor of fertility outcomes. Regardless of literacy status, women with secondary or higher education experience later first births and lower completed fertility than less-educated women. Years of schooling also play a role in fertility outcomes. The longer women remain in primary school, the later their first birth and the fewer children they have, underscoring the crucial role of school duration in shaping reproductive behaviours. These findings reinforce previous research showing that education, particularly from the secondary level, is a strong driver of fertility reduction (Bongaarts 2010; Shapiro 2012; Shapiro & Tenikue 2015).

Nevertheless, literacy, within education levels, has a modest but significant effect. In particular, among women with no or only primary education, those who are literate tend to have fewer children than their illiterate counterparts. One plausible explanation, though untested in this study, is that literate women may better understand print and media messages about family planning. This access to information may enable them to make informed reproductive choices (Iacoella et al. 2022; LeVine et al. 2011). The relationship between individual literacy and first birth timing appears to vary with the country's literacy prevalence. In areas where literacy is limited, it does not significantly alter the timing of first births among less-educated women. By contrast, in countries with widespread literacy prevalence, literate women tend to postpone childbirth slightly more than their illiterate counterparts. This delay may reflect processes such as diffusion, social learning and better employment opportunities, among other factors (Adhikari et al. 2024; Asongu et al. 2021; Kravdal 2012). In some countries, a significant proportion of women with primary education remain illiterate, which may help explain why fertility differences between women with no education and those with primary education are smaller than expected.

An unexpected finding emerges when controlling for the length of schooling: illiterate women with primary education display a higher mean age at first birth than their literate counterparts. This pattern has been documented in least-developed countries (Martin 1995). Several possible explanations can be proposed for this pattern. Women with some literacy may be perceived as more desirable in the marriage market, leading to earlier marriage and childbearing (Qian & Qian 2017). Alternatively, illiterate women may remain in school longer because of repetition linked to poor performance. This extended time in school increases their total years of schooling, subsequently delaying their entry into marriages and age at first birth (Ndaruhutse 2008; Wills 2023). However, even when school duration is controlled for, literate women still have fewer children than women with lower literacy levels, particularly those who were illiterate. According to the "quality over quantity" theory, investments in human capital such as literacy raise the opportunity cost of childbearing, leading to lower fertility rates (Becker et al. 2010). Supporting this view, Jun and Lee (2014) demonstrated that education quality influences reproductive decisions, while Kim (2023) provided evidence from sub-Saharan Africa aligning with this mechanism.

Despite the insights and results from our study, it has several limitations. First, we were unable to control for contraceptive use, which may mediate the observed relationship between literacy and fertility (LeVine et al. 2011). Future studies incorporating contraceptive use data and examining family planning practices by literacy level could provide deeper insights into the mechanisms linking literacy, education, and fertility behaviour. In addition, we classified countries by primary-level literacy prevalence using a 60% threshold, reflecting the regional average. While this represents a useful heuristic, we acknowledge that literacy outcomes exist along a continuum. Future research could adopt an alternative way to model literacy prevalence in order to better capture contextual nuance.

Another limitation is the inability to account for the exact age at which women completed their education, despite evidence that this significantly influences first birth timing (Ní Bhrolcháin & Beaujouan 2012). A clearer understanding of school attendance patterns and education quality would further enhance interpretations of the impact of literacy. Irregular school attendance, particularly in rural areas, can hinder literacy acquisition (Akyeampong et al. 2007). Although our study incorporates years of schooling for primary-educated women, it cannot assess school attendance quality, which is difficult to measure in large datasets. We acknowledge that relying on literacy alone as a measure of education quality is a limitation; nonetheless, this approach enables a direct assessment of its link to fertility. Even with a modest association and potential selection effect, literacy appears to be linked to later and lower fertility among the least educated groups, possibly through increased awareness of contraceptives and family planning options (Iacoella et al. 2022; LeVine et al. 2011). Taken together, these findings suggest that while expanding access to secondary schooling remains the most effective pathway to later childbearing and lower fertility, ensuring that primary schooling results in functional literacy can also contribute to fertility decline and women's reproductive autonomy.

REFERENCES

Adhikari, S., Lutz, W., & Kebede, E. (2024). Forecasting africa's fertility decline by female education groups. *Proceedings of the National Academy of Sciences*, *121*(46), e2320247121.

Adu Boahen, E., & Yamauchi, C. (2018). The effect of female education on adolescent fertility and early marriage: Evidence from free compulsory universal basic education in ghana. *Journal of African Economies*, *27*(2), 227–248.

Akyeampong, K., Djangmah, J., Oduro, A., Seidu, A., & Hunt, F. (2007). Access to basic education in ghana: The evidence and the issues. *CREATE Country Analytic Review*.

Al Zalak, Z., & Goujon, A. (2017). *Assessment of the data quality in demographic and health surveys in egypt* (tech. rep.). Vienna Institute of Demography Working Papers.

Altinok, N., Angrist, N., & Patrinos, H. A. (2018). Global data set on education quality (1965-2015). *World Bank Policy Research Working Paper*, (8314).

Asongu, S. A., Nounamo, Y., Njangang, H., & Tadadjeu, S. (2021). Gender inclusive intermediary education, financial stability and female employment in the industry in sub-saharan africa. *Finance Research Letters*, *43*, 101968.

Barrett, G. F., & Riddell, W. C. (2016). Ageing and literacy skills: Evidence from ials, all and piaac.

Becker, S. O., Cinnirella, F., & Woessmann, L. (2010). The trade-off between fertility and education: Evidence from before the demographic transition. *Journal of Economic Growth*, *15*, 177–204.

Behrman, J. A. (2015). Does schooling affect women's desired fertility? evidence from malawi, uganda, and ethiopia. *Demography*, *52*(3), 787–809.

Bold, T., Filmer, D., Martin, G., Molina, E., Rockmore, C., Stacy, B., Svensson, J., & Wane, W. (2017). What do teachers know and do? does it matter? evidence from primary schools in africa. *Does it Matter*.

Bongaarts, J. (2010). The causes of educational differences in fertility in sub-saharan africa. *Vienna yearbook of population research*, 31–50.

Bongaarts, J. (2020). Trends in fertility and fertility preferences in sub-saharan africa: The roles of education and family planning programs. *Genus*, *76*(1), 32.

Caldwell, J. C. (1980). Mass education as a determinant of the timing of fertility decline. *Population and development review*, 225–255.

Caldwell, J. C., & Caldwell, P. (1987). The cultural context of high fertility in sub-saharan africa. *Population and development review*, 409–437.

Cheema, J. R. (2024). Difference in literacy between private and public schools: Evidence from a survey of 61 economies. *International Journal of Research in Education and Science*, *10*(2), 218–240.

Chimombo, J. P. G. (2005). Quantity versus quality in education: Case studies in malawi. *International review of education*, *51*, 155–172.

Cleland, J., Onuoha, N., & Timaeus, I. (1994). Fertility change in sub-saharan africa: A review of the evidence. *The onset of fertility transition in Sub-Saharan Africa. Ordinal editions, Liège*, 1–20.

Colleran, H., Jasienska, G., Nenko, I., Galbarczyk, A., & Mace, R. (2014). Community-level education accelerates the cultural evolution.

DeCicca, P., & Krashinsky, H. (2017). *The effect of education on overall fertility* (tech. rep.). National Bureau of Economic Research.

The dhs program. (n.d.). https://dhsprogram.com/data/data-processing.cfm#:~:text=For%5C%20the%5C%20DHS%5C%20surveys%5C%2C%5C%20this,process%5C%20survey%5C%20and%5C%20census%5C%20data.

Dunlop, C. L., Benova, L., & Campbell, O. (2018). Effect of maternal age on facility-based delivery: Analysis of first-order births in 34 countries of sub-saharan africa using demographic and health survey data. *BMJ open*, *8*(4), e020231.

Durowaa-Boateng, A., Yildiz, D., & Goujon, A. (2023). A bayesian model for the reconstruction of education-and age-specific fertility rates. *Demographic Research*, *49*, 809–848.

Ellison, J., Berrington, A., Dodd, E., & Forster, J. J. (2022). Investigating the application of generalized additive models to discrete-time event history analysis for birth events. *Demographic Research*, *47*, 647–694.

Fenske, J. (2015). African polygamy: Past and present. *Journal of Development Economics*, *117*, 58–73.

Ferré, C. (2009). Age at first child: Does education delay fertility timing? the case of kenya. *The Case of Kenya (February 1, 2009). World Bank Policy Research Working Paper*, (4833).

Gee, J. P. (1989). What is literacy. *Journal of education*, *171*(1), 18–25.

Grant, M. J. (2015). The demographic promise of expanded female education: Trends in the age at first birth in Malawi [Publisher: Wiley Online Library]. *Population and development review*, *41*(3), 409–438.

Hayase, Y., & Liaw, K.-L. (1997). Factors on polygamy in sub-saharan africa: Findings based on the demographic and health surveys. *The Developing Economies*, *35*(3), 293–327.

Heneveld, W., & Craig, H. (1996). Schools count: World bank project designs and the quality of african primary education.

Iacoella, F., Gassmann, F., & Tirivayi, N. (2022). Which communication technology is effective for promoting reproductive health? television, radio, and mobile phones in sub-saharan africa. *PLoS One*, *17*(8), e0272501.

Jun, B., & Lee, J. (2014). *The tradeoff between fertility and education: Evidence from the korean development path* (tech. rep.). FZID Discussion Paper.

Kim, J. (2023). Female education and its impact on fertility. *IZA World of Labor*.

Kirk, D., & Pillet, B. (1998). Fertility levels, trends, and differentials in sub-Saharan Africa in the 1980s and 1990s [Publisher: JSTOR]. *Studies in family planning*, 1–22.

Kouamo, R. N. (2024). School work performance in sub-saharan africa: A bivariate multilevel analysis. *International Journal of Educational Research*, *126*, 102388.

Kravdal, Ø. (2001). The importance of education for fertility in sub-saharan africa is substantially underestimated when community effects are ignored. *Memorandum fra Økonomisk institutt, Universitetet i Oslo http://urn. nb. no/URN: NBN: no-7118*.

Kravdal, Ø. (2002). Education and fertility in sub-saharan africa: Individual and community effects. *Demography*, *39*(2), 233–250.

Kravdal, Ø. (2012). Further evidence of community education effects on fertility in sub-saharan africa. *Demographic Research*, *27*, 645–680.

LeVine, R. A., LeVine, S., Schnell-Anzola, B., Rowe, M. L., & Dexter, E. (2011). *Literacy and mothering: How women's schooling changes the lives of the world's children*. Oxford University Press.

Lewin, K. M. (2009). Access to education in sub-saharan africa: Patterns, problems and possibilities. *Comparative Education*, *45*(2), 151–174.

Lloyd, C. B., Kaufman, C. E., & Hewett, P. (2000). The spread of primary schooling in sub-saharan africa: Implications for fertility change. *Population and development review*, *26*(3), 483–515.

Lumley, T. (2020). Survey: Analysis of complex survey samples [R package version 4.0].

Lutz, W., Goujon, A., Kc, S., Stonawski, M., & Stilianakis, N. (2018). *Demographic and human capital scenarios for the 21st century: 2018 assessment for 201 countries*. Publications Office of the European Union.

Lutz, W., Reiter, C., Özdemir, C., Yildiz, D., Guimaraes, R., & Goujon, A. (2021). Skills-adjusted human capital shows rising global gap. *Proceedings of the National Academy of Sciences*, *118*(7), e2015826118.

Mahy, M., & Gupta, N. (2001). Trends and differentials in age at first birth in sub-Saharan Africa. *presentation at the XXIVth IUSSP General Population Conference Session S*, *43*.

Martin, T. C. (1995). Women's education and fertility: Results from 26 demographic and health surveys. *Studies in family planning*, 187–202.

Maruatona, T. (2008). Reflections on policies for mass literacy education in sub-saharan africa. *International Review of Education/Internationale Zeitschrift Für Erziehungswissenschaft/Revue Internationale De L'education*, *54*(5/6), 745–754.

May, J. F., & Rotenberg, S. (2020). A Call for Better Integrated Policies to Accelerate the Fertility Decline in Sub-Saharan Africa [Publisher: Wiley Online Library]. *Studies in Family Planning*, *51*(2), 193–204.

McMillan, L., & O'Neil, M. (2012). Literacy and social equity. *Counterpoints*, *406*, 30–44.

MEASURE DHS. (2008). Demographic and health surveys model woman's questionnaire with hiv/aids and malaria modules.

Myrskylä, M., Goldstein, J. R., & Cheng, Y.-h. A. (2013). New cohort fertility forecasts for the developed world: Rises, falls, and reversals. *Population and Development Review*, *39*(1), 31–56.

Ndaruhutse, S. (2008). Grade repetition in primary schools in sub-saharan africa: An evidence base for change.

Neels, K., & De Wachter, D. (2010). Postponement and recuperation of belgian fertility: How are they related to rising female educational attainment? *Vienna Yearbook of Population Research*, 77–106.

Neels, K., Murphy, M., Bhrolcháin, M. N., & Beaujouan, É. (2017). Rising educational participation and the trend to later childbearing. *Population and Development Review*, *43*(4), 667.

Ní Bhrolcháin, M., & Beaujouan, É. (2012). Fertility postponement is largely due to rising educational enrolment. *Population studies*, *66*(3), 311–327.

Nishimura, M., & Byamugisha, A. (2011). The challenges of universal primary education policy in sub-saharan africa. In *Policy debates in comparative, international, and development education* (pp. 225–245). Springer.

Obeng Gyimah, S. (2003). A cohort analysis of the timing of first birth and fertility in Ghana [Publisher: Springer]. *Population Research and Policy Review*, *22*(3), 251–266.

Oye, M., Pritchett, L., & Sandefur, J. (2016). Girls' schooling is good, girls' schooling with learning is better. *Background Paper for The Learning Generation. The Education Commission*.

Parikh, K. S., & Gupta, C. (2001). How effective is female literacy in reducing fertility? *Economic and Political Weekly*, 3391–3398.

Post, D. (2016). Adult literacy benefits? new opportunities for research into sustainable development. *International Review of Education*, *62*, 751–770.

Pritchett, L., & Sandefur, J. (2020). Girls' schooling and women's literacy: Schooling targets alone won't reach learning goals. *International Journal of Educational Development*, *78*, 102242.

Qian, Y., & Qian, Z. (2017). Assortative mating by education and hukou in shanghai. *Chinese Sociological Review*, *49*(3), 239–262.

Reiter, C. (2022). Changes in literacy skills as cohorts age. *Population and Development Review*, *48*(1), 217–246.

Ritchie, H., Samborska, V., Ahuja, N., Ortiz-Ospina, E., & Roser, M. (2023). Global education. our world in data.

Romuald, N. K. (2023). An analysis of inequalities in school performance between public and private students in sub-saharan africa. *International Journal of Educational Development*, *100*, 102802.

Roser, M., & Ortiz-Ospina, E. (2018). Literacy [https://ourworldindata.org/literacy]. *Our World in Data*.

Rossi, P. (2019). Strategic choices in polygamous households: Theory and evidence from senegal. *The Review of Economic Studies*, *86*(3), 1332–1370.

Rutstein, S. O., & Rojas, G. (2006). Guide to dhs statistics. demographic and health surveys. *Maryland: ORC Macro Calverton*.

Schoumaker, B. (2011). Omissions of births in dhs birth histories in sub-saharan africa: Measurement and determinants. *Population Association of America*.

Schoumaker, B. (2017). African fertility changes. In *Africa's population: In search of a demographic dividend* (pp. 197–211). Springer.

Schoumaker, B. D., & Sánchez-Páez, D. A. (2024). Disruptions in educational progress and fertility dynamics by educational level: Unraveling the link between education and fertility stalls in sub-saharan africa. *Population and Development Review*, *50*(1), 59–85.

Schultz, T. P. (1997). Demand for children in low income countries. *Handbook of population and family economics*, *1*, 349–430.

Shapiro, D. (2012). Women's education and fertility transition in sub-saharan africa. *Vienna Yearbook of Population Research*, 9–30.

Shapiro, D., & Tenikue, M. (2015). Women's education, infant and child mortality, and fertility decline in sub-saharan africa: A quantitative assessment. *Luxembourg Institute of Socio-Economic Research (LISER) Working Paper Series*, *7*.

Shapiro, D., & Tenikue, M. (2017). Women's education, infant and child mortality, and fertility decline in urban and rural sub-saharan africa. *Demographic Research*, *37*, 669–708.

Smith-Greenaway, E. (2015). Educational attainment and adult literacy: A descriptive account of 31 sub-saharan africa countries. *Demographic research*, *33*, 1015.

Sobotka, T., Beaujouan, É., & Van Bavel, J. (2017). Introduction: Education and fertility in low-fertility settings. *Vienna Yearbook of Population Research*, *15*, 1–16.

Somerset, A. (2009). Universalising primary education in kenya: The elusive goal. *Comparative Education*, *45*(2), 233–250.

Tabutin, D., Schoumaker, B., & Rabenoro, M. (2004). The demography of sub-saharan africa from the 1950s to the 2000s. *Population*, *59*(3), 455–555.

Tooley, J., & Dixon, P. (2005). Private education is good for the poor: A study of private schools serving the poor in low-income countries.

UNICEF. (2023). *Education data* [UNICEF DATA]. Retrieved November 23, 2023, from https://data.unicef.org/resources/how-are-children-progressing-through-school/

United Nations. (2019, December). Potential impact of later childbearing on future population.

United Nations Population Division. (n.d.). Population division data portal [Accessed: 2023-8-29]. https://population.un.org/dataportal/home

United Nations Statistics Division. (n.d.). Methodology [Accessed: 2023-8-29]. https://unstats.un.org/unsd/methodology/m49/

Uwakwe, C., Falaye, A. O., Emunemu, B. O., & Adelore, O. (2008). Impact of decentralization and privatization on the quality of education in sub-saharan africa: The nigerian experience. *European Journal of social sciences*, *7*(1), 160–170.

Wills, G. (2023). Early grade repetition in south africa.

Wood, S. N. (2017). *Generalized additive models: An introduction with r*. Chapman; Hall/CRC.

Appendix A

We present the countries and the survey years used in the analysis in Table A1.

Table A1: Countries and year of survey included in the study.

Country	Survey Year
Angola	2011, 2016
Benin	1996, 2001, 2006, 2012, 2018
Burkina Faso	1992, 1998, 2003, 2010
Burundi	1987, 2010, 2016
Cameroon	1991, 1998, 2018, 2004, 2011
Central African Republic	1994
Chad	1996, 2004, 2014
Comoros	1996, 2012
Congo	2005, 2012
Cote D'Ivoire	1994, 1998, 2012
Democratic Republic of Congo	2007, 2013
Eswatini	2006
Ethiopia	1992, 1997, 2003, 2008, 2011
Gabon	2000, 2012
Gambia	2013, 2019
Ghana	1988, 1993, 1999, 2003, 2008, 2014
Guinea	1999, 2005, 2012, 2018
Kenya	1988, 1993, 1998, 2003, 2009, 2014
Lesotho	2004, 2009, 2014
Liberia	1986, 2007, 2009, 2013, 2019
Madagascar	1992, 1997, 2004, 2008
Malawi	1992, 2000, 2004, 2010, 2015
Mali	1987, 1995, 2001, 2006, 2013, 2018
Mozambique	1997, 2003, 2011
Namibia	1992, 2000, 2006, 2013
Niger	1992, 1998, 2006, 2012
Nigeria	1990, 2003, 2008, 2010, 2013, 2018
Rwanda	1992, 2000, 2005, 2011, 2014, 2019
Sao Tome and Principe	2008
Senegal	1986, 1993, 1997, 2005, 2008, 2013, 2014, 2015, 2017, 2018
Sierra Leone	2008, 2013, 2019
South Africa	1998, 2016
Sudan	1989
Tanzania	1992, 1996, 1999, 2010, 2015
Togo	1988, 1998, 2014
Uganda	1988, 1995, 2001, 2006, 2011, 2016
Zambia	1992, 1996, 2002, 2007, 2014, 2018
Zimbabwe	1989, 1994, 2005, 2011, 2015

Table A2 shows the number of observations in the final dataset for completed fertility and age at first birth. This table does not include the observations for years of schooling.

Table A2: Final observations included in the study (Unweighted N).

Education and Literacy	Observation: Mean Age at first birth	Observation: Completed fertility
No Education and Illiterate	24,933	18,454
No Education and Semi-literate	2,172	2,171
No Education and Literate	1,252	1,223
Primary Education and Illiterate	10,854	9,546
Primary Education and Semi-literate	9,114	8,328
Primary Education and Literate	11,368	9,998
Secondary Education	14,102	10,636
Higher Education	4,485	3,453

Appendix B

In Figure B1, we compare the fitted values of a Poisson regression against a GAM and the survey mean age at first birth. To check how well the GAM explains mean age at first birth from the data, we test the predictive power of both a Poisson and a GAM without any covariates. We calculate the mean of the age at first birth by country, year of birth, level of education and literacy for women aged 40 to 50 at the time of the survey and then apply our model.

The GAM is defined as;

$$E(\text{Mean age at first birth}) = \beta_0 + \sum_p \beta_p(\text{s}(\text{Year of birth})_{\text{country}}).$$

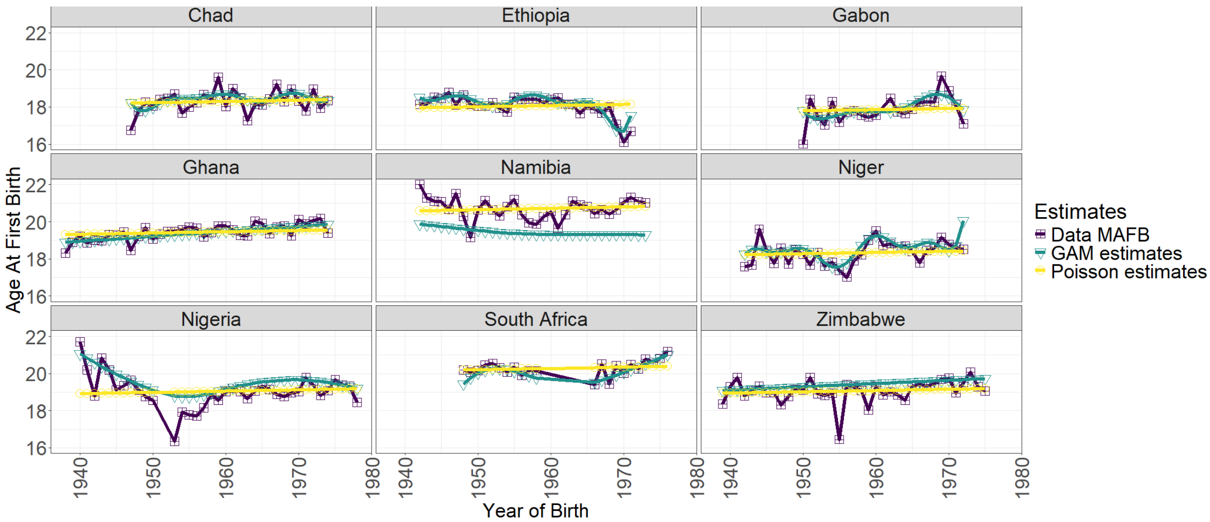
We estimate the expectation of mean age at first birth in the GAM to add the intercept to a smoothing term of year of birth by each country. Likewise, we estimate the log of the expectation of mean age at first birth as the sum of the intercept, year of birth, and country estimates.

The Poisson regression model is defined as;

$$\log(E(\text{Mean age at first birth})) = \beta_0 + \beta_p(\text{Year of birth}) + \sum_q \beta_q(\text{country}).$$

We show the predicted estimates of both models for some selected countries in Figure B1. In countries like Gabon and Chad, the GAM captures and smooths out the fluctuations in reported mean age at first birth (MAFB), whereas the Poisson fails.

Figure B1: Comparison of mean age at first birth for selected Sub-Saharan African countries.



Appendix C

We present the full results of the model presented in the main text in Table 1. We show the full model estimates of estimated mean age at first birth and completed fertility in Table C1. For all the tables containing the full results, including Appendix D, the standard errors are presented in brackets. The figures presented are the estimates and the standard errors in brackets for the parameters. In the smoothed terms, the figures provided are effective degrees of freedom (edfs) and reference degrees of freedom (Ref.df) in brackets.

Table C1: Coefficients and standard errors from selected GAM for estimated mean age at first birth and completed fertility

Parameter	Mean age at first birth (Equation 1)	Mean number of children (Equation 2)
Intercept	23.03 [15.53; 30.53]*	6.11 [5.80; 6.42]*
No Education and Illiterate	−0.17 [−0.24; −0.11]*	0.67 [0.62; 0.72]*
No Education and Semi-literate	−0.22 [−0.41; −0.03]*	0.30 [0.16; 0.44]*
No Education and Literate	0.11 [−0.13; 0.34]	0.01 [−0.16; 0.18]
Primary Education and Illiterate	−0.06 [−0.15; 0.02]	0.39 [0.33; 0.45]*
Primary Education and Semi-literate	0.00 [−0.09; 0.10]	0.05 [−0.01; 0.12]
Primary Education and Literate	RC	RC
Secondary Education	1.41 [1.33; 1.50]*	−1.33 [−1.39; −1.28]*
Higher Education	4.01 [3.85; 4.17]*	−2.57 [−2.65; −2.48]*
Angola	RC	RC
Benin	−3.76 [−11.27; 3.74]	−0.16 [−0.50; 0.17]
Burkina Faso	−3.69 [−11.21; 3.83]	0.29 [−0.13; 0.71]
Burundi	−0.89 [−8.55; 6.76]	−0.51 [−1.57; 0.54]
Cameroon	−4.62 [−12.12; 2.89]	−0.11 [−0.43; 0.21]
Central African Republic	6.34 [−84.33; 97.00]	−0.86 [−1.58; −0.13]*
Chad	−4.80 [−12.38; 2.77]	0.56 [0.14; 0.97]*
Comoros	−3.27 [−10.79; 4.26]	−0.41 [−0.84; 0.03]
Congo	−5.61 [−13.17; 1.95]	0.18 [−1.10; 1.46]
Cote D'Ivoire	−4.35 [−11.86; 3.15]	−0.45 [−0.85; −0.05]*
Democratic Republic of Congo	−13.27 [−30.44; 3.91]	0.94 [−1.57; 3.45]
Eswatini	−15.72 [−46.87; 15.43]	−0.13 [−0.53; 0.27]
Ethiopia	−5.32 [−12.83; 2.19]	0.29 [−0.15; 0.74]
Gabon	−6.36 [−14.24; 1.52]	−0.02 [−0.46; 0.42]
Gambia	−5.13 [−13.12; 2.87]	−0.38 [−1.91; 1.15]
Ghana	−3.90 [−11.40; 3.61]	−0.50 [−0.82; −0.18]*
Guinea	−4.19 [−11.71; 3.33]	−0.18 [−0.75; 0.39]
Kenya	−4.42 [−11.92; 3.08]	0.05 [−0.27; 0.37]
Lesotho	−3.12 [−10.99; 4.74]	−1.20 [−2.41; 0.00]
Liberia	−5.37 [−12.90; 2.16]	−0.09 [−0.56; 0.37]
Madagascar	−4.01 [−11.61; 3.59]	−0.75 [−1.74; 0.23]
Malawi	−4.27 [−11.77; 3.23]	0.19 [−0.13; 0.51]
Mali	−3.89 [−11.39; 3.62]	0.31 [−0.01; 0.63]
Mozambique	−2.46 [−10.61; 5.68]	−0.17 [−2.38; 2.05]
Namibia	−3.17 [−10.69; 4.35]	−1.02 [−1.35; −0.69]*
Niger	−5.35 [−12.88; 2.17]	1.01 [0.65; 1.37]*
Nigeria	−4.34 [−11.84; 3.16]	0.29 [−0.03; 0.60]
Rwanda	−1.88 [−9.38; 5.62]	0.11 [−0.21; 0.42]
Sao Tome and Principe	−5.48 [−14.78; 3.81]	1.30 [−3.84; 6.45]
Senegal	−3.56 [−11.07; 3.94]	−0.20 [−0.51; 0.11]
Sierra Leone	−5.37 [−14.04; 3.30]	−0.74 [−2.06; 0.57]
South Africa	−3.79 [−11.30; 3.73]	−1.86 [−2.25; −1.47]*
Sudan	12.81 [−94.27; 119.89]	−5.50 [−64.78; 53.78]
Tanzania	−4.37 [−11.88; 3.13]	−0.05 [−0.37; 0.27]
Togo	−3.43 [−10.94; 4.08]	−0.55 [−0.90; −0.21]*
Uganda	−4.90 [−12.40; 2.61]	0.90 [0.58; 1.22]*
Zambia	−5.09 [−12.60; 2.41]	0.78 [0.46; 1.10]*
Zimbabwe	−4.34 [−11.84; 3.17]	−0.58 [−0.90; −0.25]*

s(Year of birth): Angola	4.01 [−11.67; 19.69]	0.93 [−14.75; 16.61]
s(Year of birth): Benin	7.03 [−10.61; 24.67]	6.32 [−11.32; 23.96]
s(Year of birth): Burkina Faso	6.62 [−11.02; 24.26]	5.84 [−11.80; 23.48]
s(Year of birth): Burundi	8.79 [−8.85; 26.43]	7.61 [−10.03; 25.25]
s(Year of birth): Cameroon	7.47 [−10.17; 25.11]	4.83 [−12.81; 22.46]
s(Year of birth): Central African Republic	3.86 [−11.82; 19.54]	0.53 [−13.19; 14.25]
s(Year of birth): Chad	7.68 [−9.96; 25.31]	5.80 [−11.83; 23.44]
s(Year of birth): Comoros	4.90 [−12.73; 22.54]	3.65 [−13.99; 21.29]
s(Year of birth): Congo	2.38 [−13.29; 18.06]	3.34 [−12.34; 19.02]
s(Year of birth): Cote D'Ivoire	4.89 [−12.75; 22.53]	5.52 [−12.12; 23.16]
s(Year of birth): Democratic Republic of Congo	5.72 [−11.92; 23.36]	4.15 [−13.49; 21.79]
s(Year of birth): Eswatini	3.95 [−11.73; 19.63]	0.96 [−12.76; 14.68]
s(Year of birth): Ethiopia	6.85 [−10.79; 24.49]	7.18 [−10.46; 24.82]
s(Year of birth): Gabon	5.51 [−12.13; 23.15]	2.56 [−15.07; 20.20]
s(Year of birth): Gambia	2.92 [−12.76; 18.60]	2.61 [−13.06; 18.29]
s(Year of birth): Ghana	5.45 [−12.18; 23.09]	6.45 [−11.19; 24.09]
s(Year of birth): Guinea	6.10 [−11.54; 23.74]	6.34 [−11.30; 23.98]
s(Year of birth): Kenya	6.27 [−11.37; 23.91]	7.59 [−10.05; 25.23]
s(Year of birth): Lesotho	4.45 [−13.19; 22.09]	4.18 [−13.46; 21.82]
s(Year of birth): Liberia	8.75 [−8.89; 26.39]	7.40 [−10.24; 25.04]
s(Year of birth): Madagascar	6.25 [−11.39; 23.89]	6.37 [−11.27; 24.01]
s(Year of birth): Malawi	7.54 [−10.10; 25.18]	5.92 [−11.72; 23.56]
s(Year of birth): Mali	8.41 [−9.23; 26.05]	7.71 [−9.93; 25.35]
s(Year of birth): Mozambique	7.45 [−10.19; 25.09]	7.47 [−10.17; 25.11]
s(Year of birth): Namibia	7.62 [−10.02; 25.26]	4.43 [−13.21; 22.07]
s(Year of birth): Niger	7.89 [−9.75; 25.53]	6.25 [−11.39; 23.89]
s(Year of birth): Nigeria	8.65 [−8.98; 26.29]	7.89 [−9.75; 25.53]
s(Year of birth): Rwanda	7.49 [−10.15; 25.13]	7.05 [−10.59; 24.69]
s(Year of birth): Sao Tome and Principe	2.23 [−13.45; 17.91]	2.46 [−13.22; 18.14]
s(Year of birth): Senegal	6.96 [−10.68; 24.60]	7.82 [−9.82; 25.46]
s(Year of birth): Sierra Leone	4.75 [−12.89; 22.39]	3.96 [−11.72; 19.64]
s(Year of birth): South Africa	4.18 [−13.46; 21.82]	4.68 [−12.96; 22.32]
s(Year of birth): Sudan	3.75 [−11.93; 19.43]	3.53 [−12.15; 19.21]
s(Year of birth): Tanzania	7.77 [−9.87; 25.41]	6.61 [−11.03; 24.25]
s(Year of birth): Togo	7.57 [−10.07; 25.21]	6.48 [−11.16; 24.12]
s(Year of birth): Uganda	7.93 [−9.71; 25.57]	8.19 [−9.45; 25.83]
s(Year of birth): Zambia	7.58 [−10.06; 25.22]	7.32 [−10.32; 24.95]
s(Year of birth): Zimbabwe	2.24 [−15.40; 19.88]	5.44 [−12.20; 23.08]
AIC	42304.01	34256.42
BIC	44316.06	36077.10
Log Likelihood	−20874.26	−16877.14
Deviance	1437709.93	120040.18
Deviance explained	0.54	0.74
Dispersion	139.35	11.55
R^2	0.52	0.73
GCV score	402793.12	275873.03
Num. obs.	10345	10422
Num. smooth terms	38	38

* Null hypothesis value outside the confidence interval. RC - Reference Category

Similar to Table C1, we show the results of the model for only education level separately for countries where literacy is "widespread" and "limited" (as described in the method section of the main text Equations 3 and 4 in Tables C2 and C3).

Table C2: Coefficients and standard errors of GAM for mean age at first birth by education level, grouped by literacy prevalence at primary education

Parameter	Widespread	Limited
Intercept	21.99 [20.62; 23.35]*	22.83 [15.48; 30.19]*
No Education and Illiterate	−0.57 [−0.67; −0.47]*	−0.01 [−0.10; 0.08]
No Education and Semi-literate	−0.15 [−0.43; 0.13]	−0.22 [−0.46; 0.03]
No Education and Literate	0.19 [−0.08; 0.45]	−0.21 [−0.60; 0.18]
Primary Education and Illiterate	−0.40 [−0.56; −0.23]*	0.08 [−0.03; 0.18]
Primary Education and Semi-literate	−0.22 [−0.37; −0.08]*	0.15 [0.03; 0.27]*

Primary and Literate	RC	RC
Secondary Education	1.57 [1.43; 1.70]*	1.46 [1.35; 1.57]*
Higher Education	4.36 [4.05; 4.67]*	4.03 [3.84; 4.23]*
Burundi	RC	
Eswatini	−13.17 [−40.26; 13.92]	
Lesotho	−2.07 [−5.00; 0.85]	
Madagascar	−2.86 [−4.67; −1.04]*	
Namibia	−2.01 [−3.41; −0.61]*	
Rwanda	−0.65 [−2.02; 0.72]	
South Africa	−2.81 [−4.24; −1.37]*	
Tanzania	−3.14 [−4.51; −1.77]*	
Zimbabwe	−3.21 [−4.58; −1.84]*	
Angola		RC
Benin		−3.71 [−11.06; 3.65]
Burkina Faso		−3.66 [−11.04; 3.71]
Cameroon		−4.53 [−11.88; 2.82]
Central African Republic		6.47 [−82.98; 95.92]
Chad		−4.74 [−12.17; 2.70]
Comoros		−3.21 [−10.59; 4.17]
Congo		−5.50 [−12.91; 1.92]
Cote D'Ivoire		−4.30 [−11.66; 3.06]
Democratic Republic of Congo		−12.86 [−29.64; 3.92]
Ethiopia		−5.29 [−12.66; 2.07]
Gabon		−6.24 [−13.97; 1.50]
Gambia		−5.07 [−12.90; 2.77]
Ghana		−3.82 [−11.17; 3.54]
Guinea		−4.15 [−11.52; 3.22]
Kenya		−4.31 [−11.66; 3.04]
Liberia		−5.30 [−12.68; 2.08]
Malawi		−4.19 [−11.55; 3.16]
Mali		−3.84 [−11.19; 3.51]
Mozambique		−2.41 [−10.51; 5.69]
Niger		−5.37 [−12.75; 2.01]
Nigeria		−4.28 [−11.63; 3.07]
Sao Tome and Principe		−5.38 [−14.48; 3.73]
Senegal		−3.50 [−10.85; 3.85]
Sierra Leone		−5.29 [−13.78; 3.21]
Sudan		12.32 [−93.72; 118.36]
Togo		−3.38 [−10.73; 3.98]
Uganda		−4.81 [−12.16; 2.54]
Zambia		−4.99 [−12.34; 2.36]
s(Year of birth): Burundi	8.81 [−8.83; 26.45]	
s(Year of birth): Eswatini	3.99 [−11.69; 19.67]	
s(Year of birth): Lesotho	4.76 [−10.92; 20.44]	
s(Year of birth): Madagascar	6.81 [−10.82; 24.45]	
s(Year of birth): Namibia	7.72 [−9.92; 25.36]	
s(Year of birth): Rwanda	7.68 [−9.96; 25.32]	
s(Year of birth): South Africa	4.95 [−12.69; 22.59]	
s(Year of birth): Tanzania	7.81 [−9.83; 25.45]	
s(Year of birth): Zimbabwe	7.03 [−10.61; 24.67]	
s(Year of birth): Angola		3.98 [−11.70; 19.66]
s(Year of birth): Benin		6.96 [−10.68; 24.60]
s(Year of birth): Burkina Faso		6.59 [−11.05; 24.23]
s(Year of birth): Cameroon		7.43 [−10.20; 25.07]
s(Year of birth): Central African Republic		3.83 [−11.85; 19.51]
s(Year of birth): Chad		7.65 [−9.99; 25.29]
s(Year of birth): Comoros		4.85 [−12.79; 22.48]
s(Year of birth): Congo		2.36 [−13.32; 18.04]
s(Year of birth): Cote D'Ivoire		4.67 [−12.97; 22.31]
s(Year of birth): Democratic Republic of Congo		5.69 [−11.95; 23.33]
s(Year of birth): Ethiopia		6.82 [−10.82; 24.46]
s(Year of birth): Gabon		5.46 [−12.18; 23.10]
s(Year of birth): Gambia		2.88 [−12.80; 18.56]
s(Year of birth): Ghana		4.72 [−12.92; 22.36]
s(Year of birth): Guinea		6.06 [−11.58; 23.70]

s(Year of birth): Kenya		6.21 [−11.43; 23.85]
s(Year of birth): Liberia		8.74 [−8.90; 26.38]
s(Year of birth): Malawi		7.49 [−10.14; 25.13]
s(Year of birth): Mali		8.37 [−9.27; 26.01]
s(Year of birth): Mozambique		7.43 [−10.21; 25.07]
s(Year of birth): Niger		7.88 [−9.76; 25.52]
s(Year of birth): Nigeria		8.64 [−9.00; 26.28]
s(Year of birth): Sao Tome and Principe		2.19 [−13.49; 17.87]
s(Year of birth): Senegal		6.87 [−10.77; 24.51]
s(Year of birth): Sierra Leone		4.73 [−12.91; 22.37]
s(Year of birth): Sudan		3.72 [−11.96; 19.40]
s(Year of birth): Togo		7.54 [−10.10; 25.18]
s(Year of birth): Uganda		7.92 [−9.72; 25.56]
s(Year of birth): Zambia		7.54 [−10.09; 25.18]
AIC	9315.26	32776.84
BIC	9763.91	34266.41
Log Likelihood	−4580.56	−16174.66
Deviance	253978.41	1168405.25
Deviance explained	0.67	0.43
Dispersion	102.15	149.22
R^2	0.66	0.41
GCV score	93251.01	308368.43
Num. obs.	2494	7851
Num. smooth terms	9	29

* Null hypothesis value outside the confidence interval.

Table C3: Coefficients and 95% confidence intervals for completed fertility by education level, grouped by literacy prevalence at primary education

Parameter	Widespread	Limited
Intercept	5.68 [4.69; 6.68]*	6.05 [5.74; 6.36]*
No Education and Illiterate	0.44 [0.36; 0.51]*	0.76 [0.70; 0.83]*
No Education and Semi-literate	0.22 [0.02; 0.43]*	0.36 [0.19; 0.54]*
No Education and Literate	−0.01 [−0.21; 0.18]	−0.06 [−0.33; 0.22]
Primary Education and Illiterate	0.25 [0.13; 0.38]*	0.47 [0.40; 0.54]*
Primary Education and Semi-literate	0.11 [0.01; 0.22]*	0.07 [−0.01; 0.15]
Primary and Literate	RC	RC
Secondary Education	−1.39 [−1.48; −1.30]*	−1.26 [−1.33; −1.19]*
Higher Education	−2.37 [−2.53; −2.22]*	−2.57 [−2.68; −2.46]*
Burundi	RC	
Eswatini	0.38 [−0.65; 1.40]	
Lesotho	−0.78 [−2.41; 0.86]	
Madagascar	−0.40 [−1.80; 0.99]	
Namibia	−0.51 [−1.51; 0.49]	
Rwanda	0.70 [−0.29; 1.70]	
South Africa	−1.40 [−2.42; −0.37]*	
Tanzania	0.51 [−0.49; 1.51]	
Zimbabwe	−0.07 [−1.07; 0.93]	
Angola		RC
Benin		−0.20 [−0.54; 0.14]
Burkina Faso		0.25 [−0.19; 0.68]
Cameroon		−0.12 [−0.44; 0.20]
Central African Republic		−0.84 [−1.59; −0.10]*
Chad		0.53 [0.11; 0.95]*
Comoros		−0.44 [−0.88; −0.00]*
Congo		0.17 [−1.07; 1.41]
Cote D’Ivoire		−0.49 [−0.90; −0.07]*
Democratic Republic of Congo		0.90 [−1.55; 3.35]
Ethiopia		0.28 [−0.19; 0.74]
Gabon		−0.03 [−0.47; 0.42]
Gambia		−0.41 [−1.87; 1.06]
Ghana		−0.53 [−0.85; −0.20]*

Guinea		−0.24 [−0.80; 0.31]
Kenya		0.05 [−0.27; 0.37]
Liberia		−0.14 [−0.60; 0.32]
Malawi		0.18 [−0.14; 0.50]
Mali		0.27 [−0.05; 0.59]
Mozambique		−0.23 [−2.59; 2.14]
Niger		1.00 [0.64; 1.37]*
Nigeria		0.27 [−0.05; 0.59]
Sao Tome and Principe		1.30 [−3.79; 6.40]
Senegal		−0.24 [−0.55; 0.08]
Sierra Leone		−0.78 [−2.06; 0.50]
Sudan		−5.96 [−67.64; 55.73]
Togo		−0.58 [−0.93; −0.24]*
Uganda		0.90 [0.57; 1.22]*
Zambia		0.78 [0.46; 1.10]*
s(Year of birth): Burundi	7.70 [−9.94; 25.34]	
s(Year of birth): Eswatini	0.97 [−12.75; 14.69]	
s(Year of birth): Lesotho	4.46 [−11.22; 20.14]	
s(Year of birth): Madagascar	7.03 [−10.61; 24.67]	
s(Year of birth): Namibia	4.82 [−12.82; 22.46]	
s(Year of birth): Rwanda	7.31 [−10.33; 24.94]	
s(Year of birth): South Africa	5.09 [−12.55; 22.73]	
s(Year of birth): Tanzania	6.80 [−10.84; 24.44]	
s(Year of birth): Zimbabwe	5.92 [−11.72; 23.56]	
s(Year of birth): Angola		0.93 [−14.75; 16.61]
s(Year of birth): Benin		6.28 [−11.36; 23.92]
s(Year of birth): Burkina Faso		5.80 [−11.84; 23.44]
s(Year of birth): Cameroon		4.77 [−12.87; 22.41]
s(Year of birth): Central African Republic		0.54 [−13.18; 14.26]
s(Year of birth): Chad		5.78 [−11.86; 23.42]
s(Year of birth): Comoros		3.59 [−14.05; 21.23]
s(Year of birth): Congo		3.28 [−12.40; 18.96]
s(Year of birth): Cote D'Ivoire		5.47 [−12.17; 23.11]
s(Year of birth): Democratic Republic of Congo		4.12 [−13.52; 21.76]
s(Year of birth): Ethiopia		7.15 [−10.49; 24.79]
s(Year of birth): Gabon		2.56 [−15.08; 20.20]
s(Year of birth): Gambia		2.55 [−13.13; 18.23]
s(Year of birth): Ghana		6.37 [−11.27; 24.01]
s(Year of birth): Guinea		6.29 [−11.35; 23.93]
s(Year of birth): Kenya		7.55 [−10.09; 25.19]
s(Year of birth): Liberia		7.33 [−10.31; 24.97]
s(Year of birth): Malawi		5.47 [−12.17; 23.11]
s(Year of birth): Mali		8.47 [−9.17; 26.11]
s(Year of birth): Mozambique		7.46 [−10.18; 25.10]
s(Year of birth): Niger		6.20 [−11.44; 23.84]
s(Year of birth): Nigeria		7.89 [−9.75; 25.53]
s(Year of birth): Sao Tome and Principe		2.45 [−13.23; 18.13]
s(Year of birth): Senegal		7.81 [−9.83; 25.45]
s(Year of birth): Sierra Leone		3.92 [−11.76; 19.60]
s(Year of birth): Sudan		3.53 [−12.15; 19.21]
s(Year of birth): Togo		6.41 [−11.23; 24.05]
s(Year of birth): Uganda		8.06 [−9.57; 25.70]
s(Year of birth): Zambia		7.25 [−10.39; 24.89]
AIC	7443.62	26702.20
BIC	7837.53	28051.69
Log Likelihood	−3654.22	−13157.66
Deviance	23324.74	95956.60
Deviance explained	0.80	0.70
Dispersion	9.32	12.16
R^2	0.79	0.68
GCV score	63752.86	211478.58
Num. obs.	2510	7912
Num. smooth terms	9	29

* Null hypothesis value outside the confidence interval.

Table C4 shows the full results of the model for primary educated women with a focus on surveys after 2000 (Models 5 and 6) and without controlling for years of schooling.

Table C4: Coefficients and 95% confidence intervals for completed fertility and age at first birth only for primary education.

Parameter	Mean age at first birth (Equation 5)	Mean age at first birth	Completed fertility (Equation 6)	Completed fertility
Intercept	21.38 [19.03; 23.74]*	21.41 [19.12; 23.70]*	6.35 [5.42; 7.28]*	6.27 [5.28; 7.26]*
Primary Education and Illiterate	0.21 [0.11; 0.30]*	−0.06 [−0.14; 0.02]	0.19 [0.12; 0.27]*	0.47 [0.41; 0.54]*
Primary Education and Semi-literate	0.18 [0.09; 0.28]*	0.05 [−0.04; 0.14]	−0.05 [−0.12; 0.02]	0.08 [0.01; 0.15]*
Primary Education and Literate	RC	RC	RC	RC
Years of schooling: 0	−0.21 [−0.50; 0.07]		0.11 [−0.11; 0.32]	
Years of schooling: 1	−0.31 [−0.47; −0.14]*		0.34 [0.22; 0.47]*	
Years of schooling: 2	−0.25 [−0.39; −0.11]*		0.26 [0.15; 0.37]*	
Years of schooling: 3	−0.20 [−0.32; −0.07]*		0.25 [0.15; 0.34]*	
Years of schooling: 4	−0.18 [−0.30; −0.05]*		0.13 [0.04; 0.23]*	
Years of schooling: 5	RC		RC	
Years of schooling: 6	0.04 [−0.08; 0.15]		−0.13 [−0.22; −0.05]*	
Years of schooling: 7	0.47 [0.33; 0.61]*		−0.43 [−0.53; −0.33]*	
Years of schooling: 8	0.93 [0.73; 1.14]*		−0.76 [−0.90; −0.61]*	
Years of schooling: 9	1.62 [0.27; 2.97]*		−1.34 [−2.24; −0.44]*	
Years of schooling: 10+	3.39 [1.26; 5.53]*		−2.22 [−3.41; −1.02]*	
Angola	RC	RC	RC	RC
Benin	−1.65 [−4.02; 0.71]	−1.65 [−3.96; 0.65]	−1.23 [−2.17; −0.29]*	−1.20 [−2.21; −0.20]*
Burkina Faso	−2.54 [−5.08; 0.01]	−2.51 [−5.00; −0.02]*	−1.33 [−3.10; 0.44]	−1.30 [−3.06; 0.45]
Burundi	−0.26 [−2.65; 2.13]	−0.33 [−2.66; 2.00]	0.41 [−1.01; 1.83]	0.47 [−0.92; 1.86]
Cameroon	−2.96 [−5.32; −0.60]*	−2.91 [−5.21; −0.61]*	−0.45 [−1.39; 0.48]	−0.49 [−1.49; 0.51]
Chad	−3.02 [−5.39; −0.65]*	−3.01 [−5.33; −0.70]*	1.16 [0.19; 2.13]*	1.18 [0.15; 2.22]*
Comoros	−2.53 [−5.29; 0.24]	−2.52 [−5.31; 0.26]	−3.19 [−13.57; 7.18]	−3.33 [−13.18; 6.52]
Congo	−3.22 [−5.71; −0.72]*	−3.16 [−5.60; −0.72]*	−1.56 [−3.61; 0.48]	−1.59 [−3.66; 0.49]
Cote D'Ivoire	−2.99 [−5.39; −0.60]*	−2.96 [−5.29; −0.62]*	−1.01 [−2.01; −0.02]*	−1.03 [−2.09; 0.02]
Democratic Republic of Congo	−2.95 [−5.41; −0.49]*	−2.93 [−5.33; −0.53]*	0.33 [−0.71; 1.37]	0.35 [−0.74; 1.44]
Eswatini	−4.01 [−6.49; −1.53]*	−3.94 [−6.35; −1.54]*	−0.41 [−2.19; 1.37]	−0.53 [−2.12; 1.07]
Ethiopia	−3.45 [−7.72; 0.81]	−3.52 [−7.63; 0.58]	−0.09 [−1.45; 1.27]	−0.10 [−1.39; 1.18]
Gabon	−3.61 [−6.83; −0.39]*	−3.62 [−6.80; −0.44]*	2.47 [−11.42; 16.36]	2.50 [−12.00; 17.01]
Gambia	−2.74 [−5.24; −0.24]*	−2.59 [−5.03; −0.14]*	−1.30 [−5.36; 2.76]	−1.48 [−5.69; 2.73]
Ghana	−2.72 [−5.09; −0.35]*	−2.61 [−4.93; −0.30]*	−1.25 [−2.28; −0.23]*	−1.30 [−2.38; −0.22]*
Guinea	−2.92 [−5.33; −0.52]*	−2.84 [−5.19; −0.50]*	−0.62 [−1.62; 0.37]	−0.67 [−1.72; 0.39]
Kenya	−3.39 [−5.75; −1.04]*	−3.05 [−5.35; −0.75]*	−0.14 [−1.07; 0.80]	−0.41 [−1.41; 0.59]
Lesotho	−2.06 [−4.43; 0.31]	−1.86 [−4.17; 0.45]	−1.49 [−2.45; −0.54]*	−1.63 [−2.65; −0.61]*
Liberia	−3.51 [−5.89; −1.14]*	−3.46 [−5.78; −1.15]*	−0.15 [−1.12; 0.83]	−0.15 [−1.19; 0.88]
Madagascar	−1.60 [−4.06; 0.86]	−1.51 [−4.14; 1.12]	−1.46 [−9.46; 6.55]	−1.28 [−9.24; 6.67]
Malawi	−3.12 [−5.48; −0.77]*	−3.01 [−5.30; −0.71]*	0.31 [−0.64; 1.26]	0.26 [−0.76; 1.27]
Mali	−2.48 [−4.86; −0.11]*	−2.44 [−4.76; −0.13]*	−0.13 [−1.09; 0.83]	−0.14 [−1.17; 0.88]
Mozambique	−4.45 [−9.25; 0.36]	−4.53 [−9.36; 0.31]	−0.98 [−2.42; 0.45]	−0.92 [−2.40; 0.57]
Namibia	−1.92 [−4.31; 0.47]	−1.90 [−4.24; 0.44]	−1.23 [−2.18; −0.29]*	−1.15 [−2.27; −0.02]*
Niger	−0.71 [−4.82; 3.40]	−0.75 [−4.78; 3.28]	−1.56 [−5.06; 1.93]	−1.39 [−4.81; 2.03]
Nigeria	−2.63 [−4.99; −0.28]*	−2.51 [−4.81; −0.21]*	0.13 [−0.81; 1.06]	−0.01 [−1.01; 0.99]
Rwanda	0.07 [−2.29; 2.42]	0.14 [−2.15; 2.44]	−0.41 [−1.34; 0.52]	−0.43 [−1.43; 0.56]
Sao Tome and Principe	−2.79 [−5.25; −0.33]*	−2.85 [−5.26; −0.44]*	−0.17 [−2.11; 1.76]	−0.13 [−2.08; 1.82]
Senegal	−1.15 [−3.51; 1.21]	−1.13 [−3.43; 1.17]	−1.32 [−2.26; −0.39]*	−1.31 [−2.31; −0.31]*
Sierra Leone	−2.88 [−5.50; −0.26]*	−2.80 [−5.35; −0.24]*	−0.42 [−1.67; 0.83]	−1.46 [−3.62; 0.70]
South Africa	−2.60 [−5.81; 0.61]	−2.44 [−5.60; 0.72]	−2.26 [−3.86; −0.67]*	−2.37 [−3.95; −0.78]*
Tanzania	−3.04 [−5.55; −0.53]*	−2.69 [−5.17; −0.22]*	−0.30 [−1.30; 0.71]	−0.58 [−1.63; 0.48]
Togo	4.32 [−12.64; 21.29]	4.31 [−12.05; 20.68]	−2.22 [−5.72; 1.29]	−2.22 [−5.65; 1.20]
Uganda	−3.36 [−5.71; −1.00]*	−3.30 [−5.60; −1.00]*	0.78 [−0.15; 1.72]	0.76 [−0.24; 1.75]
Zambia	−3.64 [−6.00; −1.28]*	−3.44 [−5.74; −1.15]*	0.64 [−0.29; 1.57]	0.48 [−0.52; 1.48]
Zimbabwe	−3.15 [−5.51; −0.78]*	−2.97 [−5.28; −0.66]*	−0.87 [−1.81; 0.08]	−1.02 [−2.02; −0.01]*
s(Year of birth): Angola	5.57 [−12.07; 23.21]	5.52 [−12.12; 23.16]	4.61 [−13.03; 22.25]	4.69 [−12.95; 22.33]
s(Year of birth): Benin	7.26 [−10.38; 24.90]	7.25 [−10.39; 24.89]	7.40 [−10.24; 25.04]	7.72 [−9.92; 25.36]
s(Year of birth): Burkina Faso	2.92 [−14.72; 20.56]	2.86 [−14.78; 20.50]	4.85 [−12.79; 22.49]	4.73 [−12.91; 22.37]
s(Year of birth): Burundi	1.78 [−15.86; 19.42]	1.66 [−15.98; 19.30]	4.86 [−12.77; 22.50]	4.67 [−12.97; 22.31]
s(Year of birth): Cameroon	6.64 [−11.00; 24.28]	6.60 [−11.04; 24.24]	5.83 [−11.81; 23.47]	5.83 [−11.81; 23.47]

s(Year of birth): Chad	3.13 [−14.51; 20.77]	3.11 [−14.52; 20.75]	5.13 [−12.51; 22.77]	4.99 [−12.65; 22.63]
s(Year of birth): Comoros	0.78 [−14.90; 16.46]	0.86 [−14.82; 16.54]	3.50 [−12.18; 19.18]	3.43 [−12.25; 19.11]
s(Year of birth): Congo	4.23 [−13.41; 21.87]	4.20 [−13.44; 21.84]	6.17 [−11.47; 23.81]	6.15 [−11.49; 23.79]
s(Year of birth): Cote D'Ivoire	0.00 [−15.68; 15.68]	0.01 [−15.67; 15.69]	0.77 [−14.91; 16.45]	0.79 [−14.89; 16.47]
s(Year of birth): Democratic Republic of Congo	6.14 [−11.50; 23.78]	6.10 [−11.54; 23.74]	5.77 [−11.87; 23.41]	5.66 [−11.98; 23.30]
s(Year of birth): Eswatini	0.72 [−14.96; 16.40]	0.61 [−15.07; 16.29]	1.83 [−13.85; 17.51]	1.57 [−14.11; 17.25]
s(Year of birth): Ethiopia	7.27 [−10.37; 24.91]	7.20 [−10.44; 24.84]	6.03 [−11.61; 23.67]	5.72 [−11.92; 23.36]
s(Year of birth): Gabon	3.08 [−12.60; 18.76]	3.07 [−12.61; 18.75]	5.34 [−10.34; 21.02]	5.38 [−10.30; 21.06]
s(Year of birth): Gambia	0.86 [−16.78; 18.50]	0.87 [−16.77; 18.51]	5.21 [−12.43; 22.85]	5.24 [−12.40; 22.88]
s(Year of birth): Ghana	0.90 [−16.74; 18.54]	0.87 [−16.77; 18.51]	7.59 [−10.05; 25.23]	7.49 [−10.15; 25.13]
s(Year of birth): Guinea	6.56 [−11.08; 24.20]	6.58 [−11.06; 24.22]	5.28 [−12.36; 22.92]	5.32 [−12.32; 22.96]
s(Year of birth): Kenya	4.37 [−13.27; 22.01]	5.09 [−12.54; 22.73]	6.57 [−11.07; 24.21]	6.87 [−10.77; 24.51]
s(Year of birth): Lesotho	5.14 [−12.50; 22.78]	5.04 [−12.60; 22.68]	6.35 [−11.29; 23.99]	6.52 [−11.12; 24.16]
s(Year of birth): Liberia	4.56 [−13.08; 22.20]	4.29 [−13.35; 21.93]	6.17 [−11.47; 23.81]	5.97 [−11.67; 23.61]
s(Year of birth): Madagascar	3.19 [−14.45; 20.83]	4.19 [−13.45; 21.83]	6.61 [−11.03; 24.25]	6.60 [−11.04; 24.24]
s(Year of birth): Malawi	5.84 [−11.80; 23.48]	5.91 [−11.73; 23.55]	7.88 [−9.76; 25.52]	7.89 [−9.75; 25.53]
s(Year of birth): Mali	2.29 [−15.35; 19.93]	2.27 [−15.37; 19.91]	7.26 [−10.38; 24.90]	7.25 [−10.39; 24.89]
s(Year of birth): Mozambique	7.43 [−10.21; 25.07]	7.43 [−10.20; 25.07]	6.44 [−11.20; 24.08]	6.44 [−11.20; 24.08]
s(Year of birth): Namibia	3.50 [−14.14; 21.14]	3.88 [−13.75; 21.52]	0.95 [−16.69; 18.59]	5.27 [−12.37; 22.91]
s(Year of birth): Niger	6.22 [−11.42; 23.86]	6.18 [−11.46; 23.82]	6.66 [−10.98; 24.30]	6.61 [−11.03; 24.25]
s(Year of birth): Nigeria	6.77 [−10.87; 24.41]	6.78 [−10.86; 24.42]	6.30 [−11.34; 23.94]	6.34 [−11.30; 23.98]
s(Year of birth): Rwanda	6.40 [−11.24; 24.04]	6.75 [−10.89; 24.39]	6.98 [−10.66; 24.62]	6.71 [−10.93; 24.35]
s(Year of birth): Sao Tome and Principe	1.02 [−14.66; 16.70]	1.04 [−14.64; 16.72]	2.55 [−13.13; 18.23]	2.52 [−13.16; 18.20]
s(Year of birth): Senegal	6.60 [−11.04; 24.23]	6.61 [−11.03; 24.25]	7.75 [−9.89; 25.39]	7.74 [−9.90; 25.38]
s(Year of birth): Sierra Leone	6.50 [−11.14; 24.14]	6.46 [−11.18; 24.10]	6.42 [−11.22; 24.06]	7.52 [−10.12; 25.16]
s(Year of birth): South Africa	1.54 [−14.14; 17.22]	1.52 [−14.16; 17.20]	1.56 [−14.12; 17.24]	1.49 [−14.19; 17.17]
s(Year of birth): Tanzania	5.10 [−12.54; 22.74]	5.20 [−12.44; 22.84]	4.16 [−13.48; 21.80]	4.06 [−13.58; 21.70]
s(Year of birth): Togo	4.80 [−10.88; 20.48]	4.77 [−10.91; 20.45]	3.61 [−12.07; 19.29]	3.56 [−12.12; 19.24]
s(Year of birth): Uganda	7.68 [−9.96; 25.32]	7.81 [−9.83; 25.45]	6.15 [−11.49; 23.79]	6.23 [−11.41; 23.87]
s(Year of birth): Zambia	6.69 [−10.95; 24.33]	6.60 [−11.04; 24.24]	6.55 [−11.09; 24.19]	6.56 [−11.08; 24.20]
s(Year of birth): Zimbabwe	5.63 [−12.01; 23.27]	5.80 [−11.84; 23.44]	5.63 [−12.01; 23.27]	5.80 [−11.84; 23.44]
AIC	59533.27	59730.73	52192.96	52515.73
BIC	61095.93	61236.77	54008.52	54295.54
Log Likelihood	−29556.12	−29662.48	−25852.23	−26018.43
Deviance	1153163.19	1173164.94	107106.16	109992.90
Deviance explained	0.27	0.26	0.28	0.26
Dispersion	93.38	94.99	8.59	8.82
R^2	0.26	0.25	0.27	0.25
GCV score	456437.38	457506.09	312154.33	313829.91
Num. obs.	12370	12370	12498	12498
Num. smooth terms	36	36	36	36

* Null hypothesis value outside the confidence interval. RC- Reference category.

Appendix D

We run the following interaction GAMs for age at first birth and number of children ever born respectively and present the results in Table D1.

$$E(\text{age at first birth}) = \beta_0 + \beta_j \cdot \text{Country}_j + \sum_p \beta_p(\text{s}(\text{Year of birth})_{\text{country}}) \tag{7}$$

$$+\beta_m \cdot \text{Education}_m + \beta_n \cdot \text{Literacy}_n + \beta_r \cdot \text{Education} \times \text{Literacy}_r .$$

$$E(\text{number of children ever born}) = \beta_0 + \beta_j \cdot \text{Country}_j + \sum_p \beta_p(\text{s}(\text{Year of birth})_{\text{country}}) \tag{8}$$

$$+\beta_m \cdot \text{Education}_m + \beta_n \cdot \text{Literacy}_n + \beta_r \cdot \text{Education} \times \text{Literacy}_r .$$

Table D1: Coefficients and standard errors of GAM for completed fertility and age at first birth with interaction

Parameter	Mean age at first birth (Equation 7)	Mean number of children (Equation 8)
Intercept	23.03 [15.51; 30.55]*	6.00 [5.59; 6.42]*
No Education	−0.22 [−0.42; −0.02]*	0.41 [0.10; 0.72]*
Primary Education	RC	RC
Secondary Education	1.44 [1.15; 1.73]*	−1.07 [−1.30; −0.84]*
Higher Education	4.02 [3.69; 4.36]*	−2.28 [−2.52; −2.03]*
Illiterate	−0.64 [−1.09; −0.19]*	0.51 [0.23; 0.78]*
Semi-literate	RC	RC
Literate	−0.02 [−0.30; 0.27]	−0.18 [−0.35; −0.01]*
No Education:Illiterate	0.69 [0.20; 1.17]*	−0.13 [−0.44; 0.18]
No Education:Semi-literate	0.00 [0.00; 0.00]	0.00 [0.00; 0.00]
No Education:Literate	0.34 [−0.07; 0.75]	−0.11 [−0.38; 0.16]
Primary Education:Illiterate	0.57 [0.11; 1.03]*	0.00 [0.00; 0.00]
Primary Education:Semi-literate	0.00 [0.00; 0.00]	0.16 [−0.13; 0.45]
Primary Education:Literate	0.01 [−0.29; 0.31]	0.28 [0.05; 0.52]*
Other	RC	RC
Angola	RC	RC
Benin	−3.76 [−11.28; 3.76]	−0.17 [−0.51; 0.17]
Burkina Faso	−3.69 [−11.23; 3.85]	0.28 [−0.14; 0.70]
Burundi	−0.89 [−8.57; 6.78]	−0.52 [−1.57; 0.53]
Cameroon	−4.59 [−12.11; 2.93]	−0.12 [−0.44; 0.20]
Central African Republic	6.33 [−84.36; 97.03]	−0.86 [−1.60; −0.12]*
Chad	−4.80 [−12.39; 2.79]	0.55 [0.13; 0.97]*
Comoros	−3.26 [−10.81; 4.28]	−0.41 [−0.84; 0.02]
Congo	−5.61 [−13.19; 1.97]	0.19 [−1.09; 1.46]
Cote D’Ivoire	−4.35 [−11.88; 3.17]	−0.45 [−0.85; −0.05]*
Democratic Republic of Congo	−13.27 [−30.46; 3.92]	0.93 [−1.57; 3.43]
Eswatini	−15.70 [−46.82; 15.43]	−0.13 [−0.53; 0.27]
Ethiopia	−5.31 [−12.84; 2.22]	0.29 [−0.16; 0.74]
Gabon	−6.36 [−14.26; 1.53]	−0.02 [−0.46; 0.42]
Gambia	−5.12 [−13.13; 2.88]	−0.38 [−1.78; 1.01]
Ghana	−3.83 [−11.35; 3.69]	−0.57 [−0.89; −0.25]*
Guinea	−4.19 [−11.73; 3.35]	−0.19 [−0.76; 0.38]
Kenya	−4.42 [−11.94; 3.10]	0.05 [−0.27; 0.37]
Lesotho	−3.12 [−11.01; 4.76]	−1.20 [−2.41; 0.01]
Liberia	−5.36 [−12.91; 2.18]	−0.10 [−0.56; 0.37]
Madagascar	−4.01 [−11.63; 3.61]	−0.76 [−1.75; 0.23]
Malawi	−4.27 [−11.79; 3.25]	0.18 [−0.14; 0.50]
Mali	−3.88 [−11.40; 3.64]	0.30 [−0.01; 0.62]
Mozambique	−2.45 [−10.61; 5.70]	−0.18 [−2.39; 2.04]
Namibia	−3.17 [−10.71; 4.36]	−1.02 [−1.35; −0.69]*
Niger	−5.35 [−12.89; 2.19]	1.00 [0.64; 1.37]*
Nigeria	−4.34 [−11.86; 3.18]	0.28 [−0.04; 0.60]
Rwanda	−1.88 [−9.40; 5.65]	0.10 [−0.22; 0.42]
Sao Tome and Principe	−5.48 [−14.81; 3.84]	1.30 [−3.85; 6.45]
Senegal	−3.56 [−11.08; 3.96]	−0.20 [−0.52; 0.11]

Sierra Leone	−5.37 [−14.06; 3.32]	−0.75 [−2.07; 0.58]
South Africa	−3.79 [−11.32; 3.74]	−1.86 [−2.25; −1.47]*
Sudan	12.86 [−94.40; 120.12]	−5.58 [−65.02; 53.85]
Tanzania	−4.37 [−11.89; 3.15]	−0.06 [−0.38; 0.26]
Togo	−3.43 [−10.95; 4.10]	−0.56 [−0.90; −0.21]*
Uganda	−4.89 [−12.42; 2.63]	0.89 [0.57; 1.21]*
Zambia	−5.09 [−12.61; 2.43]	0.78 [0.46; 1.10]*
Zimbabwe	−4.34 [−11.86; 3.18]	−0.57 [−0.90; −0.25]*
s(Year of birth): Angola	4.02 [−11.66; 19.70]	0.93 [−14.75; 16.61]
s(Year of birth): Benin	7.03 [−10.61; 24.67]	6.31 [−11.33; 23.95]
s(Year of birth): Burkina Faso	6.62 [−11.01; 24.26]	5.85 [−11.79; 23.48]
s(Year of birth): Burundi	8.79 [−8.85; 26.43]	7.61 [−10.03; 25.25]
s(Year of birth): Cameroon	7.96 [−9.68; 25.60]	4.84 [−12.80; 22.48]
s(Year of birth): Central African Republic	3.86 [−11.82; 19.54]	0.54 [−13.18; 14.26]
s(Year of birth): Chad	7.68 [−9.96; 25.32]	5.81 [−11.83; 23.45]
s(Year of birth): Comoros	4.91 [−12.73; 22.55]	3.66 [−13.98; 21.30]
s(Year of birth): Congo	2.38 [−13.30; 18.06]	3.34 [−12.34; 19.02]
s(Year of birth): Cote D'Ivoire	4.90 [−12.74; 22.54]	5.53 [−12.11; 23.17]
s(Year of birth): Democratic Republic of Congo	5.72 [−11.92; 23.36]	4.15 [−13.49; 21.79]
s(Year of birth): Eswatini	3.95 [−11.73; 19.63]	0.96 [−12.76; 14.68]
s(Year of birth): Ethiopia	6.85 [−10.79; 24.49]	7.19 [−10.45; 24.83]
s(Year of birth): Gabon	5.51 [−12.13; 23.15]	2.57 [−15.07; 20.21]
s(Year of birth): Gambia	2.91 [−12.77; 18.59]	2.50 [−13.18; 18.18]
s(Year of birth): Ghana	4.68 [−12.96; 22.32]	6.49 [−11.15; 24.13]
s(Year of birth): Guinea	6.10 [−11.54; 23.74]	6.34 [−11.30; 23.98]
s(Year of birth): Kenya	6.27 [−11.36; 23.91]	7.59 [−10.05; 25.23]
s(Year of birth): Lesotho	4.45 [−13.19; 22.09]	4.19 [−13.45; 21.83]
s(Year of birth): Liberia	8.75 [−8.89; 26.39]	7.42 [−10.22; 25.06]
s(Year of birth): Madagascar	6.25 [−11.39; 23.89]	6.39 [−11.25; 24.03]
s(Year of birth): Malawi	7.55 [−10.09; 25.18]	5.92 [−11.72; 23.56]
s(Year of birth): Mali	8.41 [−9.23; 26.05]	7.71 [−9.93; 25.35]
s(Year of birth): Mozambique	7.45 [−10.19; 25.09]	7.47 [−10.17; 25.11]
s(Year of birth): Namibia	7.62 [−10.02; 25.26]	4.43 [−13.21; 22.07]
s(Year of birth): Niger	7.89 [−9.75; 25.53]	6.26 [−11.38; 23.90]
s(Year of birth): Nigeria	8.65 [−8.99; 26.29]	7.89 [−9.75; 25.53]
s(Year of birth): Rwanda	7.49 [−10.14; 25.13]	7.05 [−10.59; 24.69]
s(Year of birth): Sao Tome and Principe	2.23 [−13.45; 17.91]	2.47 [−13.21; 18.15]
s(Year of birth): Senegal	6.97 [−10.67; 24.61]	7.82 [−9.82; 25.46]
s(Year of birth): Sierra Leone	4.75 [−12.89; 22.39]	3.97 [−11.71; 19.65]
s(Year of birth): South Africa	4.19 [−13.45; 21.83]	4.71 [−12.93; 22.35]
s(Year of birth): Sudan	3.75 [−11.93; 19.43]	3.54 [−12.14; 19.21]
s(Year of birth): Tanzania	7.77 [−9.87; 25.41]	6.60 [−11.04; 24.24]
s(Year of birth): Togo	7.57 [−10.07; 25.21]	6.48 [−11.16; 24.12]
s(Year of birth): Uganda	7.93 [−9.71; 25.57]	7.32 [−10.32; 24.96]
s(Year of birth): Zambia	7.59 [−10.05; 25.23]	7.32 [−10.32; 24.96]
s(Year of birth): Zimbabwe	2.27 [−15.37; 19.91]	5.42 [−12.22; 23.06]
AIC	42295.30	34222.84
BIC	44322.71	36052.07
Log Likelihood	−20867.79	−16859.17
Deviance	1435911.86	119627.03
Deviance explained	0.54	0.74
Dispersion	139.17	11.51
R^2	0.52	0.73
GCV score	402730.15	275690.43
Num. obs.	10345	10422
Num. smooth terms	38	38

* Null hypothesis value outside the confidence interval. RC- Reference category.

The "Other" category is the secondary and higher education levels interaction effects with literacy levels as we do not necessarily include this category in the text

2.3. Shifting spousal age gaps in Ghana and Kenya: Does education matter?

This manuscript was submitted to Demographic Research. The journal acknowledged the first submission on April 3, 2025, and accepted it on September 4, 2025. Authors: Afua Durowaa-Boateng and Dr. Endale Kebede.

Abstract: Spousal age gaps shape fertility, gender power dynamics, and female autonomy. While global trends show a decline, sub-Saharan Africa exhibits a high spousal age gap, particularly in men-older relationships. Averages only can obscure these persistent inequalities, as high spousal age gaps have implications for gender equity and fertility transitions beyond shifts in the mean. This study examines high spousal age gap trends (≥ 10 years) in Ghana and Kenya from 1990–1994 to 2020–2024 survey periods and evaluates the role of education in these shifts. Although these countries differ in sociocultural contexts, urbanisation trajectories, and education levels, both adopted Universal Primary Education policies around the same time and have extensive DHS data, offering valuable comparative cases. Using data from Demographic and Health Surveys, we apply a Kitagawa decomposition to distinguish the contributions of educational expansion from behavioural shifts within educational groups. This approach helps clarify how much of the overall decrease in age gaps is due to a larger educated population (compositional effect), versus people with the same education levels choosing similar-aged partners (behavioural effect). Results show a decline in high spousal age gaps in both countries, though the underlying mechanisms differ. In Ghana, reductions were largely driven by changes in educational composition, as more men attained higher education. In Kenya, declines were more behaviour-driven, indicating that changes in partner selection norms coincided with educational expansion. The findings suggest that male education plays an important role in partner selection, complementing the well-documented effects of female education on demographic transitions. Understanding spousal age gap dynamics could inform policies aimed at improving reproductive autonomy and gender equality in sub-Saharan Africa.

Shifting spousal age gaps in Kenya and Ghana: Does education matter?

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Abstract

BACKGROUND
Spousal age gaps shape fertility, gender power dynamics, and female autonomy. While global trends show a decline, sub-Saharan Africa exhibits a high spousal age gap, particularly in men-older relationships. Averages only can obscure these persistent inequalities, as high spousal age gaps have implications for gender equity and fertility transitions beyond shifts in the mean.

OBJECTIVE
This study examines high spousal age gap trends ($\geq$ 10 years) in Ghana and Kenya from 1990-1994 to 2020-2024 survey periods and evaluates the role of education in these shifts. Although these countries differ in sociocultural contexts, urbanisation trajectories, and education levels, both adopted Universal Primary Education policies around the same time and have extensive DHS data, offering valuable comparative cases.

METHODS
Using data from Demographic and Health Surveys, we apply a Kitagawa decomposition to distinguish the contributions of educational expansion from behavioural shifts within educational groups. This approach helps clarify how much of the overall decrease in age gaps is due to a larger educated population (compositional effect), versus people with the same education levels choosing similar-aged partners (behavioural effect).

RESULTS
Results show a decline in high spousal age gaps in both countries, though the underlying mechanisms differ. In Ghana, reductions were largely driven by changes in educational composition, as more men attained higher education. In Kenya, declines were more behaviour-driven, indicating that changes in partner selection norms coincided with educational expansion.

CONCLUSIONS
The findings suggest that male education plays an important role in partner selection, complementing the well-documented effects of female education on demographic transitions.

CONTRIBUTION
Understanding spousal age gap dynamics could inform policies aimed at improving reproductive autonomy and gender equality in sub-Saharan Africa.

1. Introduction

Spousal age gaps are a critical yet often overlooked demographic factor that influences fertility decisions, reproductive autonomy, child health, and gender power dynamics (e.g., Shephard 2019; Samuelsson 2020; Batyra et al. 2023: etc.). While global trends indicate a decline in age gaps between spouses, sub-Saharan Africa continues to exhibit some of the highest spousal age gaps (United Nations 2016; Feng and Ren 2022). These gaps are usually in "men-older" unions, and are often linked to patriarchal societies, thus, reinforcing traditional gender roles (Carmichael 2011; Gustafson and Fransson 2015). Pronounced spousal age differences, especially gaps exceeding 10 years, are linked to lower contraceptive use, reduced female autonomy, and greater gender power imbalances (Shapiro and Gebreselassie 2014; Kyei and Bawah 2024). Despite global declines in spousal age gaps, the persistence of high "male-older" spousal age gaps (hereafter spousal age gaps) in sub-Saharan Africa calls for a deeper exploration of their implications for fertility transitions, female autonomy and power dynamics.

This study examines trends in the proportion of "men-older" couples with high age gaps ($\geq$ 10 years) and mean spousal age gaps for Ghana and Kenya. The ten-year threshold for high spousal age gaps is widely used in demographic research as an indicator of substantial power imbalances in marriage (Lehmiller and Christopher 2008; Gustafson and Fransson 2015). This threshold also corresponds with the observed distribution (see Figure 1), where a marked rightward tail begins at ten years, reinforcing its appropriateness as a cut-off. Previous studies on spousal age disparities in sub-Saharan Africa also apply this benchmark to assess gendered decision-making dynamics and reproductive autonomy (Samuelsson 2020; Kyei and Bawah 2024). Ghana and Kenya offer compelling comparative cases. Both countries adopted the Universal Primary Education (UPE) policies around the same time, have relatively high levels of female education attainment compared to other sub-Saharan African countries, extensive Demographic and Health Survey (DHS) data, and differing socio-cultural contexts. Ghana, a predominantly patrilineal society with a higher acceptance of polygyny, provides an opportunity to examine spousal age gaps in a more traditional setting. In contrast, Kenya, with lower polygyny prevalence and higher female literacy, offers insight into how educational and social transitions interact with partner selection behaviours (Nishimura et al. 2009; Bado, Guengant, and Maga 2022; Tabutin et al. 2020; Kramer 2020). The acceptance of polygamy is worth mentioning as societies that are more accepting of polygyny are likely to have larger spousal age differences (Seligson and McCants 2022). This may be because in the absence of multiple women to fulfil fertility desire, the hypothesised alternative would be to marry a younger woman to fulfil childbearing needs (Tertilt 2005). Thus, in the case of Ghana, more accepting of polygyny, and Kenya, less so, the hypothesis is that the spousal age gap would be lower in the less accepting country. However, polygyny itself is not accounted for in the analysis. The interest in Ghana and Kenya is to identify whether changes in spousal age gaps reflect structural factors (e.g., higher levels of education) or behavioural ones (e.g., changing partner preferences), and what these changes may mean for gender equity in union formation.

Prior research shows that female education influences fertility and marriage timing, contributing to lower fertility rates and shifting marriage patterns (Bongaarts 2010; Chae and Agadjanian 2022). Theoretical frameworks such as assortative mating and educational hypergamy provide insights into partner selection but are often based on low fertility, high-income settings. The theory proposes that education may be linked to partner selection as individuals with similar education and socioeconomic backgrounds are more likely to partner with one another (Qian and Qian 2017; Qian 2017). Hypergamy, the concept that women "marry up" in terms of education levels; that is, women are more likely to marry partners who are better educated than themselves. However, there is a growing change in this trend where the proportions of women in such marriages are declining, although there are some regional variations (Esteve, García-Román, and Permanyer 2012; Esteve et al. 2016). These declines may be due to the improvement and changes in the distribution of the gender structure by educational attainment brought about by more women attaining equal or higher levels of education than men (Lin, Desai, and Chen 2020). These educational shifts, alongside rising urbanisation and changing gender structures among others, are central to the fertility transition theory, which posits that improvements in female education contribute to later marriages, smaller spousal age gaps, and lower fertility rates (Bongaarts 2010). This theory with its mechanisms may also hold in sub-Saharan Africa.

Due to the association between education and fertility decline, numerous studies have examined the relationship between school reform programmes and fertility outcomes, mostly focusing on female education (Ferré 2009; Adu Boahen and Yamauchi 2018; Adu Boahen 2024; Goujon 2022). Existing research on spousal gaps, including sub-Saharan African countries, and in areas of the region, focuses on female education as a driver of fertility transitions and spousal age gap reduction (e.g., Lawson et al. 2021; Batyra, Kohler, and Furstenberg 2021). However, these perspectives overlook the role of male education in shaping partner selection. Educated men tend to delay marriage due to extended schooling, career development, and shifting economic expectations (Mansour and McKinnish 2014). This delay could potentially increase their exposure to age-similar women in professional and social networks, gradually weakening traditional hypergamous preferences for significantly younger spouses and open space for more age-symmetric (homogeneous) unions. This theoretical mechanism aligns with findings from Esteve et al. (2016) and Qian (2017), who show that prolonged education and shared institutional environments foster greater age and educational homogamy in partner selection. Additionally, male educational attainment enhances economic stability, reducing the reliance on conventional marriage patterns where older, wealthier men marry younger women (Quisumbing and Hallman 2005). Given that men in sub-Saharan Africa often play a more dominant role in reproductive and marital decisions (Abbani et al. 2024; Schoumaker 2019), shifts in male education levels can significantly reshape partner selection and gender power dynamics.

The study employs demographic decomposition techniques, specifically a Kitagawa (1955) type decomposition, to examine how educational composition and behaviour within education contribute to altering the spousal age gap in these countries. Kitagawa decomposition is particularly well-suited for this study as it helps distinguish whether observed changes in age gaps are primarily due to shifts in educational attainment or evolving preferences for partner age gaps within educational categories. Studying these countries helps evaluate whether increasing education levels contributes to reducing spousal age gaps. Thus, the research questions are as follows:

1. How have spousal age gaps changed in Ghana and Kenya from 1990-1994 to 2020-2024 survey period?
2. Does male education play a stronger role in reducing high age gaps than female or the couples' joint educational combinations?
3. To what extent do changes in educational composition versus partner selection behaviours explain the changes in the mean spousal age gap?

This study offers a nuanced understanding of gender power dynamics by shifting attention from mean spousal age gaps to extreme disparities ($\geq$ 10 years). Reducing spousal age gaps is important not only for promoting gender equity within marriage but also for improving reproductive autonomy, communication, and shared decision-making in unions. Narrow age gaps are associated with more egalitarian household dynamics and better health outcomes for women (Carmichael 2011; Adebowale 2018). In this study and throughout the remainder sections, spousal age gaps will refer to "men-older" relationships.

2. Background

Shifts in spousal age gaps are crucial indicators of fertility transitions, shifting from high to low fertility rates. Larger spousal age gaps, especially during early stages of fertility transitions, reflect traditional gender hierarchies and norms favouring early marriage for women and delayed marriage for men (Lee 2002; Lesthaeghe 2014; Van Zanden 2011). While most world regions are experiencing later ages at union and a corresponding closer gender gap, sub-Saharan Africa is amidst a transition characterised by early marriage, childbearing and significant gender gaps (Frejka 2010; Bongaarts and Blanc 2015; Church et al. 2023). In sub-Saharan Africa, expansion in education led to increases in age at marriage for women, where early marriage was a longstanding norm (Shapiro and Gebreselassie 2014; Garenne 2004). Despite these changes, the region has one of the highest spousal age gaps (Bongaarts, Mensch, and Blanc 2017; Ausubel et al. 2022).

The persistent high age gaps in sub-Saharan Africa may be attributed to entrenched social norms that view significant spousal age differences as acceptable or desirable (Hertrich 2017). Furthermore, from a viewpoint of evolutionary biology and social anthropology, men are more likely to marry younger women for a variety of reasons ranging from younger women having longer childbearing ages for more children, to care in older ages (Gustafson and Fransson 2015; Mignot 2010). Although hypergamy was introduced conceptually, our analysis could not test its decline directly due to small sample limitations. Nonetheless, the observed narrowing of age gaps is consistent with broader shifts in educational assortative mating reported in other studies.

In women, education, particularly higher education, plays a role in delaying union formation through various mechanisms. Since higher education takes time, women usually postpone entering unions and having their first children until completing school (Schultz 1997). As more women in society attain higher education levels and experience delayed union formation, other lesser-educated individuals follow this behavioural pattern, and this slowly transforms an early marriage society into a later one (Kravdal 2002, 2001; Adhikari, Lutz, and Kebede 2024). Furthermore, changes in the female educational composition led to increases in the mean age at first marriage (Bongaarts, Mensch, and Blanc 2017; Garenne 2004). Inasmuch as education delays marriage among women, highly educated men are as likely to delay marriage (Quisumbing and Hallman 2005; Dudel, Cheng, and Klüsener 2023; Mooyaart, Liefbroer, and Billari 2022; Keldal and Şeker 2022). However, the impact of education on men regarding age at marriage is not as strong as for women (Marini 1978).

In men, delaying marriage usually stems from the pressure to provide economic security, thus reflecting in the historically older ages at which men marry (Mensch, Singh, and Casterline 2005). The financial opportunities presented, at least for men with higher education, contribute to delays in marriage while increasing economic possibilities (Musick, Brand, and Davis 2012). These patterns intersect with gendered power dynamics. When only men are more educated and older, traditional power structures may be reinforced. It is unclear how this relationship changes the high age gap proportions in sub-Saharan Africa and the contribution of these education levels to the overall changes in the spousal age gap. In this regard, while answering the outlined research questions, the study checks whether men and women and indeed couples with higher levels of education (secondary or more), have smaller spousal age gaps than other groups.

Although Ghana and Kenya implemented UPE reforms along the same periods, as part of broader efforts to improve access to basic education (Nishimura et al. 2009; Babalola 2013), their sociocultural, demographic, and economic trajectories have diverged considerably. For instance, the attitudes surrounding polygyny are far more favourable in Ghana compared to Kenya, highlighting the more patrilineal outlook of Ghana versus Kenya (Kramer 2020). The generally favourable outlook of polygyny encourages men to marry younger women at later ages, leading to higher age gaps (Véronique 2007).

Thus, spousal age gaps may be higher in Ghana than in Kenya. Furthermore, literacy is significantly higher in Kenya than in Ghana, meanwhile, East and Southern Africa record higher proportions of educated individuals than West and Central Africa (Smith-Greenaway 2015). The disparity in educational composition and the varying polygyny prevalence between Ghana and Kenya merits a comparative study. Given these contextual differences, studying historical and recent educational reforms in these countries may be useful in examining how these reforms have influenced marriage patterns and spousal age gaps. Despite similar educational reform trajectories, Ghana and Kenya have unique contextual differences. By comparing the two, this study gains insight into how structural versus behavioural change may play out in these diverse settings.

3. Data and methods

3.1 Data

This study uses the Kenyan and Ghanaian Demographic and Health Surveys (DHS) from 1990 to 2022 (The DHS program 2023). The analysis groups the individual survey years into five-year survey periods for comparability. The survey periods are 1990-1994, 1995-1999, 2000-2004, 2005-2009, 2010-2014 and 2020-2024[3]. The DHS survey years included for Ghana are 1993, 1999, 2003, 2008, 2014, and 2022 and for Kenya, 1993, 1998, 2003, 2009, 2014 and 2022. The study focuses only on married couples and those living in unions within the couples' recode (CR) file for only standard DHS surveys. This particular DHS file is suitable for the analysis because the couples in the files are pre-matched, reducing the risk of misreported ages. This approach avoids biases common in the women's data (individual recode, IR), where women report both their age and their partner's age, often underestimating the partner's age compared to couple-reported data (Schoumaker 2014).

The main aim of this study is to identify the role of education in shifting spousal age gaps; thus, the study collects data by level of education. The educational categories used for both men and women are none, primary and secondary+. The none and primary groups follow the exact definitions of the DHS, while the secondary+ combines the secondary and higher education groups due to small sample size. The analysis does not distinguish between different types of unions, that is, polygynous or monogamous. First, the study calculates these measures, mean spousal age gaps and above ten-year couple proportions, by only female education (all female sample who are in a union), then by only the male education (all male sample who are in a union), then the joint educational

[3] To make it easier to compare the countries and due to a one-year difference in some survey years for Kenya and Ghana, the years are grouped, furthermore, each survey year falls within the corresponding five-year survey period.

pairing of spouses, that is, the specific combination of each partner's education level. Some joint educational pairings, particularly those involving highly educated women in earlier waves, contain relatively few observations. These small cell sizes can increase the variability of average spousal age gap estimates, especially in decomposition components. Such results need cautious interpretation. The study derives the spousal age gap for each country by taking the difference between the men's and women's ages at the time of the survey for each observation from the couples' recode files.

To ensure robustness, the study excludes 2,616 (about 10% in Figure A1) couples where the woman had a secondary education and the man had no education or primary education. Thus, there were 23,322 couples for the overall mean spousal age gap calculations, of which 8,951 were from Ghana and 14,371 from Kenya. The mean spousal age gap calculations include all age differences, even negative age gaps, in the sample. However, the proportions only focus on age gaps above ten years.

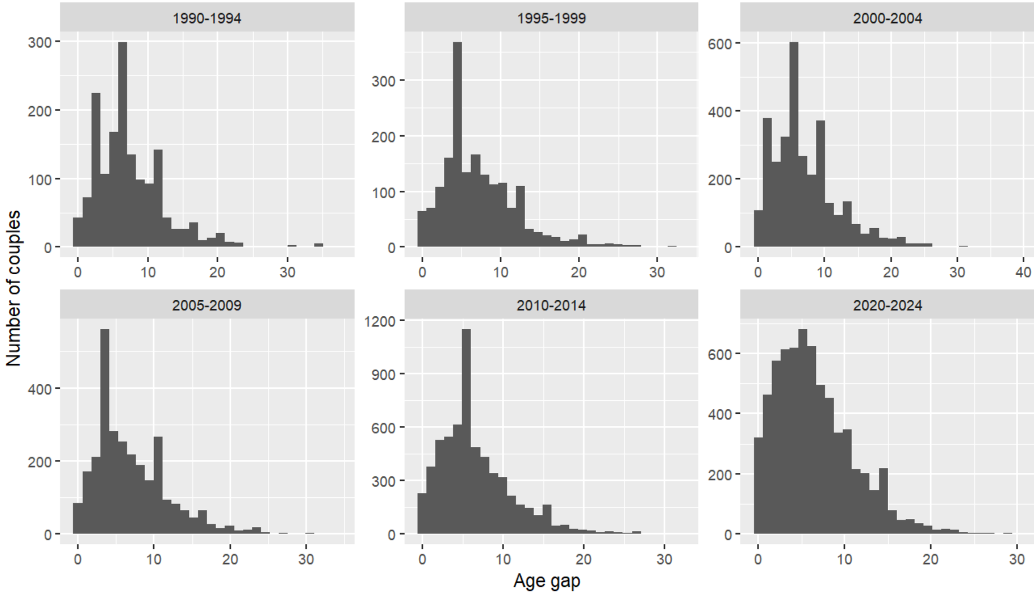
Table 1 presents the remaining sample by survey period, country and by the partnered couples' educational groups. These groups are the joint education of the couples (that is, the individual man and woman's education in the couple unit).

Table 1: Sample by joint educational combinations of couples, period and country.

Country	Male Education	Female Education	1990-1994	1995-1999	2000-2004	2005-2009	2010-2014	2020-2024	Total
Ghana	None	None	164	206	674	416	404	610	2,474
	Primary	None	82	28	153	130	105	132	630
		Primary	162	25	73	57	91	91	499
	Secondary+	None	17	85	227	203	169	243	944
		Primary	63	60	242	243	210	256	1,074
		Secondary+	22	185	606	652	674	1,191	3,330
Total			510	589	1,975	1,701	1,653	2,523	8,951
Kenya	None	None	85	48	134	107	368	400	1,142
	Primary	None	173	140	86	70	252	203	924
		Primary	472	526	539	537	2,094	1,504	5,672
	Secondary+	None	17	17	28	24	47	82	215
		Primary	216	270	232	244	820	678	2,460
		Secondary+	188	265	301	316	1,143	1,745	3,958
Total			1,151	1,266	1,320	1,298	4,724	4,612	14,371

A high age gap in this study refers to the difference in couples' ages greater than or equal to ten years. As seen in Figure 1, the distribution of age gaps shows a distinct rightward tail beginning at approximately ten years, reinforcing its appropriateness as a cut-off point. Figure 1 shows the distribution of the couples in our final sample by positive age gaps (greater than zero) for both countries. The country-specific estimates consider the survey weights through the "svydesign" function of the "survey" package within R statistical software (Lumley 2020). Using the "svyby" function within the "survey" package, the study derives the mean spousal age gap and the proportion of couples with a high age gap by country and survey period.

Figure 1: Distribution of couples by spousal gap



3.2 Methods

This study calculates the trends in spousal age gaps, including high age gaps in Ghana and Kenya across survey periods. Furthermore, it quantifies, through a decomposition approach, the contributions of compositional and behavioural changes to spousal age gaps within educational levels. The study follows a descriptive approach and presents the mean spousal age gaps and proportions of couples with high age gaps ($\geq$ 10) by country on average and by level of education. Additionally, the study analyses percentage changes in the variables between the first and last five-year survey periods. The percentage changes also include the estimations by level of education. This change for each country is as follows:

$$\Delta E_{t_{1,e}-t_{0,e}}\% = \frac{E_{t_{1,e}} - E_{t_{0,e}}}{E_{t_{0,e}}} \cdot 100\%,$$
$$\Delta E_{t_1-t_0}\% = \frac{E_{t_1} - E_{t_0}}{E_{t_0}} \cdot 100\%. \quad (1)$$

In Equation 1, the variable E represents the estimate of interest, either the mean spousal age difference or the proportion of couples with age gaps above ten years. Furthermore, t_0 is the first survey period, 1990-1994, and t_1 is the latest survey period (2020-2024), and e is the respective education level. In addition to the percentage change, the study also calculates the absolute change of the measures of interest for each country,

$E_{t_1} - E_{t_0}$. The absolute change is also by education levels. This is included to provide a more comprehensive overview of changes, particularly for small sub-groups.

Another aim of the study is to understand whether changes in the spousal age gap are attributable to shifts in the composition or behaviour of distinct educational groups within Kenya and Ghana. The decomposition analysis is performed for each of the three folds of education—women's, men's and couples' joint educational combinations. Utilising a Kitagawa (1955) type demographic decomposition technique and following Beaujouan, Zeman, and Nathan (2023), the study further decomposes the observed period differences for each country into contributions of differences in educational composition and within education group differences as:

$$\begin{aligned}
\Delta M_{t_1-t_0} &= \underbrace{\sum_e (P^e_{\geq 10,t_1} - P^e_{\geq 10,t_0})\bar{M}^e_t}_{Structural\ effect} + \underbrace{\sum_e (M^e_{t_1} - M^e_{t_0})\bar{P}^e_{\geq 10,t}}_{Rate\ effect}, \\
\bar{M}^e_t &= \frac{M^e_{t_0} + M^e_{t_1}}{2}, \\
\bar{P}^e_{\geq 10,t} &= \frac{P^e_{\geq 10,t_0} + P^e_{\geq 10,t_1}}{2}. \qquad (2)
\end{aligned}$$

The Kitagawa decomposition allows the separation of changes in spousal age gaps to shifts in the educational composition of the population versus changes in behaviour within educational groups. For instance, it helps explain if the overall age gap decreases because more people are educated (compositional effect) or because people with the same education levels are choosing similar-aged spouses (behavioural effect). In Equation 2, $\Delta M_{t_1-t_0}$ is the change in mean spousal age gap for either Ghana or Kenya between 2020-2024, t_1 and 1990-1994 t_0. M^e_t is the mean spousal age gap by each education level and $\bar{M}^e_t$ is the average of the mean spousal age gaps of 2020-2024, t_1 and 1990-1994 t_0 for each educational level. $P^e_{\geq 10,t}$ represents the proportion of couples with ten or more years age gap by level of education, while $\bar{P}^e_{\geq 10,t}$ is the average proportion of couples with an age gap above ten years between the two survey periods by level of education.

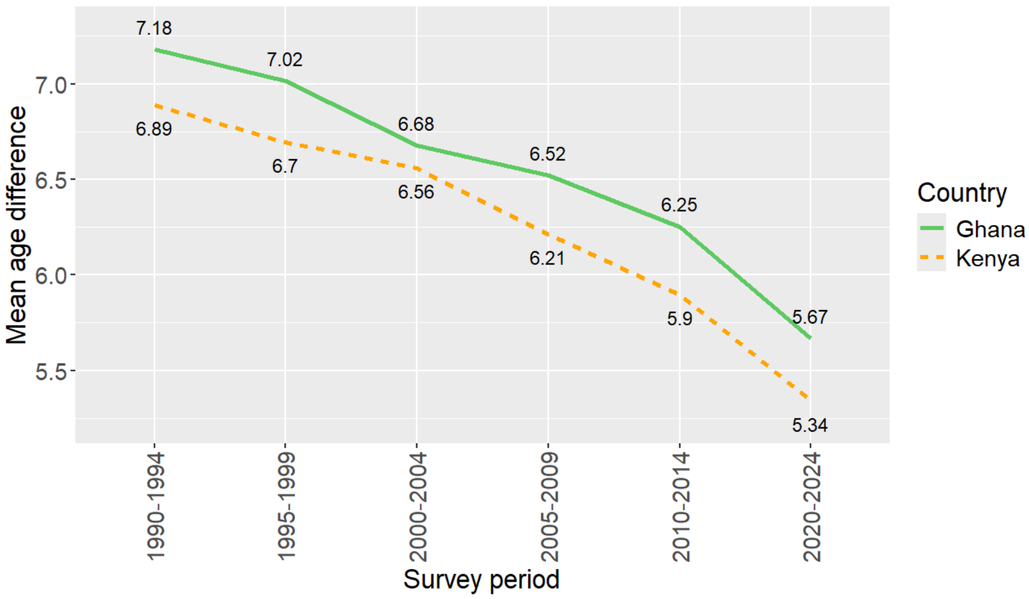
The decomposition equation described considers the contribution of changes in the proportion of couples with high spousal age gaps to the differences in mean spousal age gaps. It also examines the changes in the educational levels of these measures to the overall differences in mean spousal age gap. The structural effect (compositional effect) of Equation 2 shows the contribution of the changes in the structure (distribution) of couples with a higher or equal to ten years of age gap to the overall changes in mean spousal age gap by level of education. On the other hand, the rate effect or behavioural effect is the contribution of the changes in the patterns or behaviour of the proportion of couples with an age gap equal to or above ten years within the levels of education to the shifts in spousal age gaps. While Oaxaca-Blinder decomposition is often used to decompose differences in continuous outcomes, its application to demographic outcomes like spousal age gaps, which include both continuous (mean spousal age gap) and categorical components, can introduce challenges in interpretation. Kitagawa decomposition, in contrast, is a well-established demographic method that more precisely isolates the contributions of structural (educational composition) and behavioural (within-group changes) effects in spousal age gap trends. Given the study's focus on these two specific contributions, we employ Kitagawa decomposition as the most appropriate technique for this analysis.

4. Results

4.1 Shifts in spousal age gap

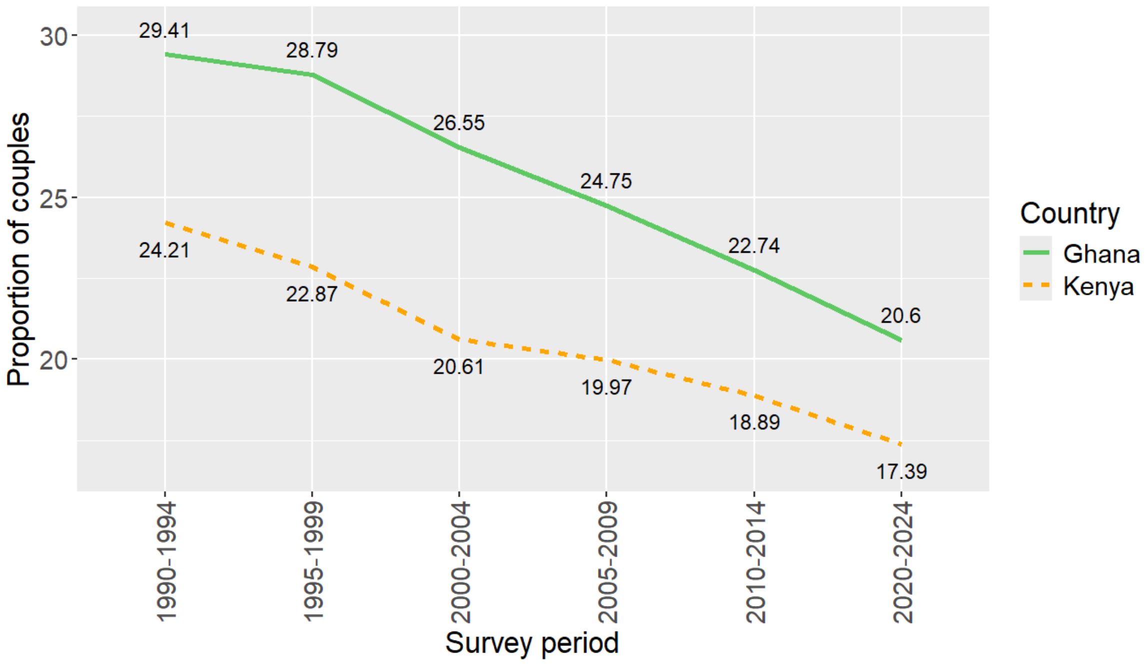
Figure 2 shows the trends in the mean spousal age gaps across the five-year survey periods for Ghana and Kenya.

Figure 2: Mean spousal age gaps trends in Ghana and Kenya.



The mean spousal age gap is declining in Ghana and Kenya across survey periods. Overall, the means observed in Ghana are consistently higher than in Kenya at any period. Figure 3 presents the proportion of couples with a ten-year or more spousal age gap in Ghana and Kenya.

Figure 3: Trends in couples proportion with high age gaps in Ghana and Kenya.

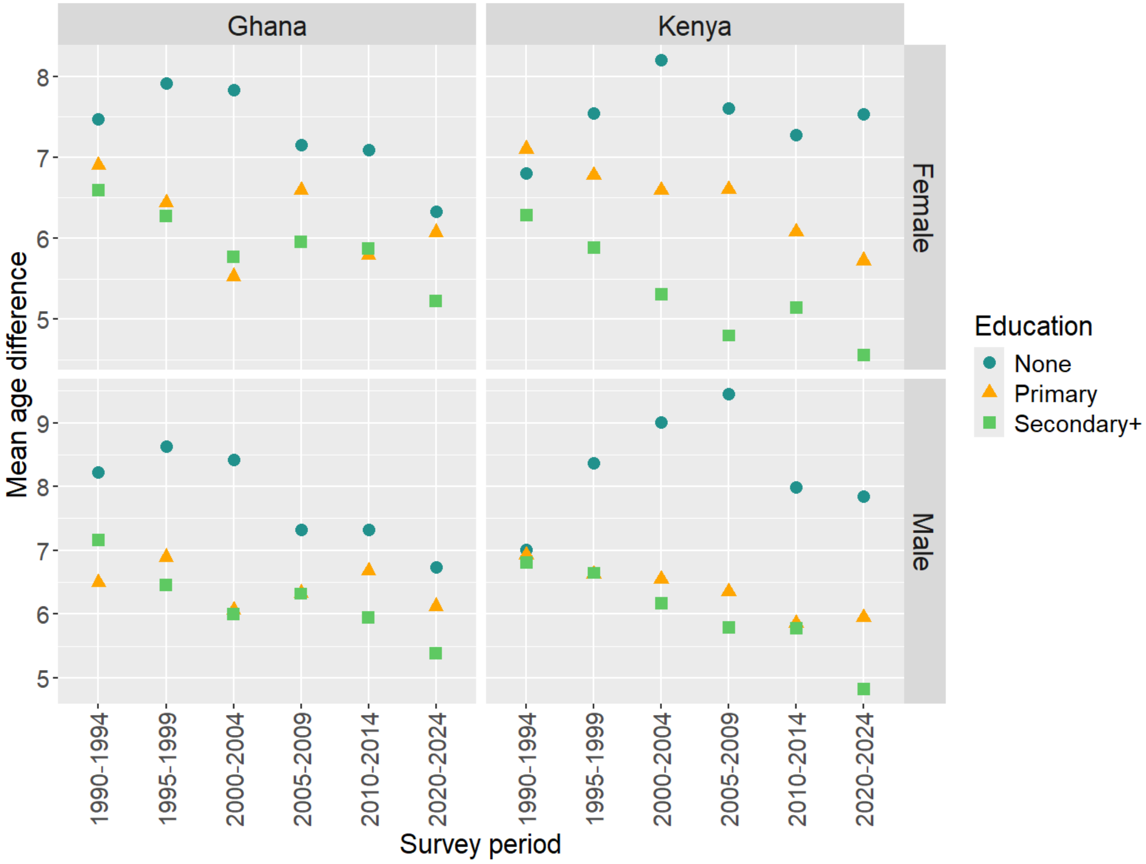


Similar to the means, the proportion of couples with a high age gap is reducing across both Kenya and Ghana. Kenya, again, has the lower proportion of couples with a high age gap across all periods. The proportions in Ghana, however, declined steeper by the last survey period compared to Kenya. Nevertheless, the proportions in Ghana were consistently above 20%, even in the latest survey.

4.2 Trends in mean age gap by levels of education

Figure 4 shows the trends in mean spousal age gap by the individual male and female levels of education for Ghana and Kenya.

Figure 4: Mean spousal age gaps among individuals currently in a union by education and gender.

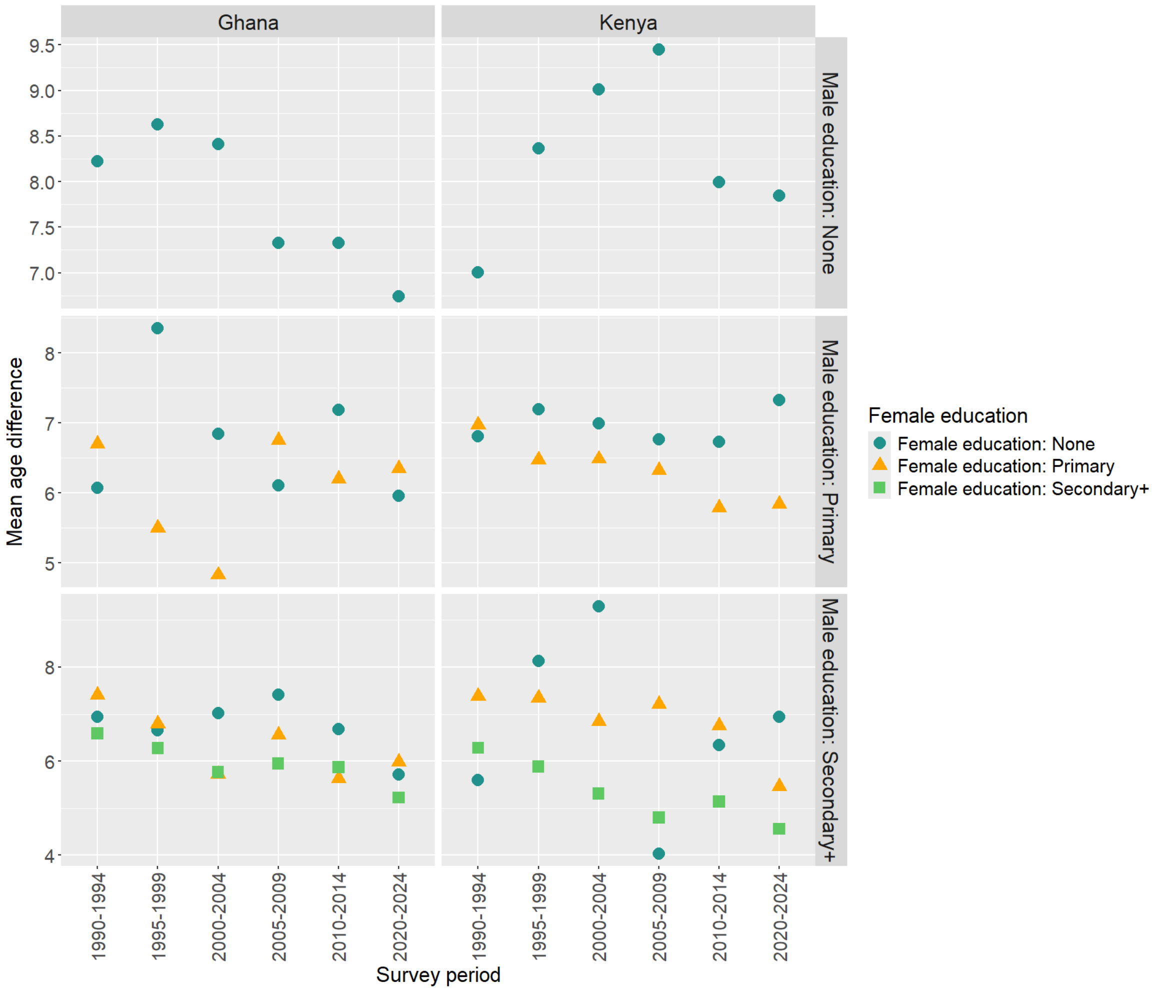


Note: Data are presented separately for men and women; not couple-level dyads.

Aside from both males and females with no education in Kenya, the mean spousal age gap declined for other education levels across the countries and survey periods. The trends by female education are generally lower (aside from women without education) in Kenya than in Ghana.

Figure 5 depicts the trends in mean spousal age gap by the individual male and female levels of education for Ghana and Kenya.

Figure 5: Mean spousal age gaps among couples by joint educational combinations



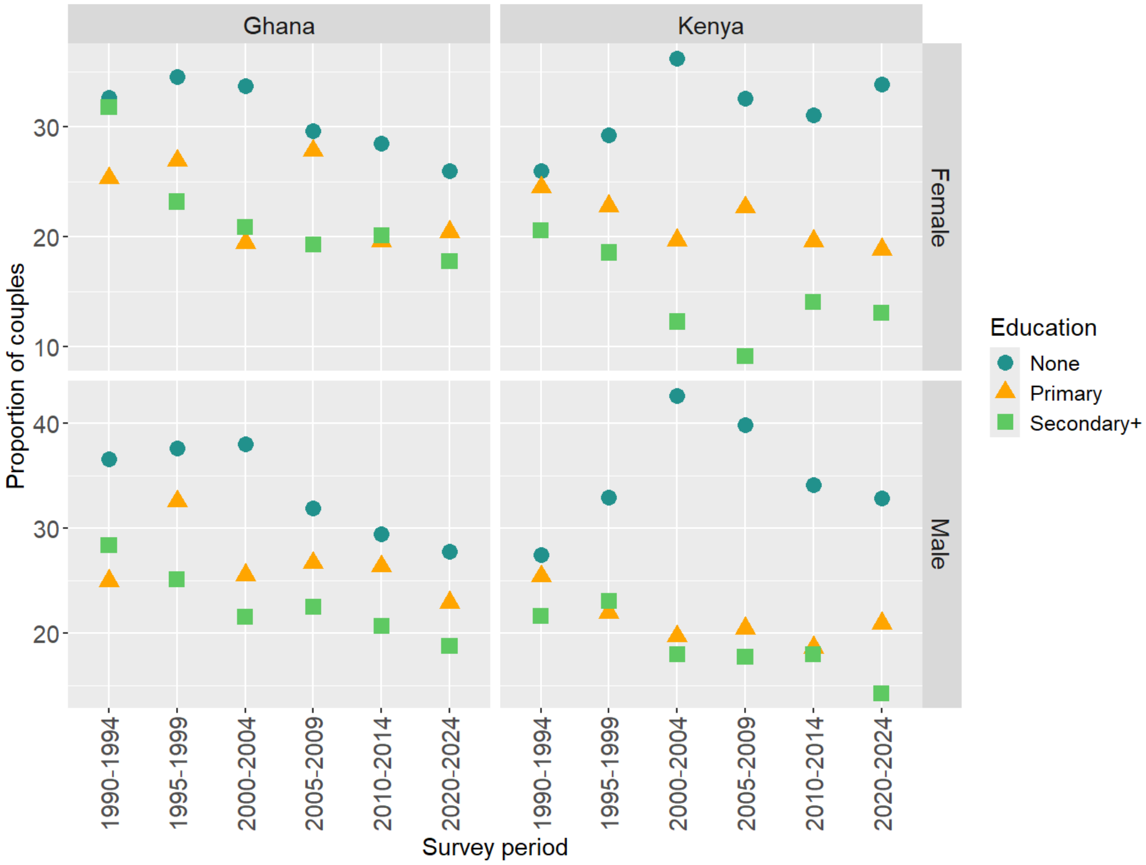
Note: Data are presented for couple-level dyads.

While there appears to be an increasing trend in the mean spousal age gap for men without education and their partners (also with no education) in Kenya, all other couples' joint educational combinations experienced declines across survey periods, albeit with varying degrees. In Kenya, men with secondary and higher education levels appear to generally have lower mean spousal age gaps with their partners than men with primary education. The trends in the mean spousal age gap in Ghana for men with secondary education and higher and their partners are generally declining. However, this decline is not visible among men with primary education and their partners.

4.3 High age gap by levels of education

Figure 6 shows the proportion of couples with a high age gap by only male and female levels of education.

Figure 6: Proportion of individuals currently in a high age gap union by country and education.

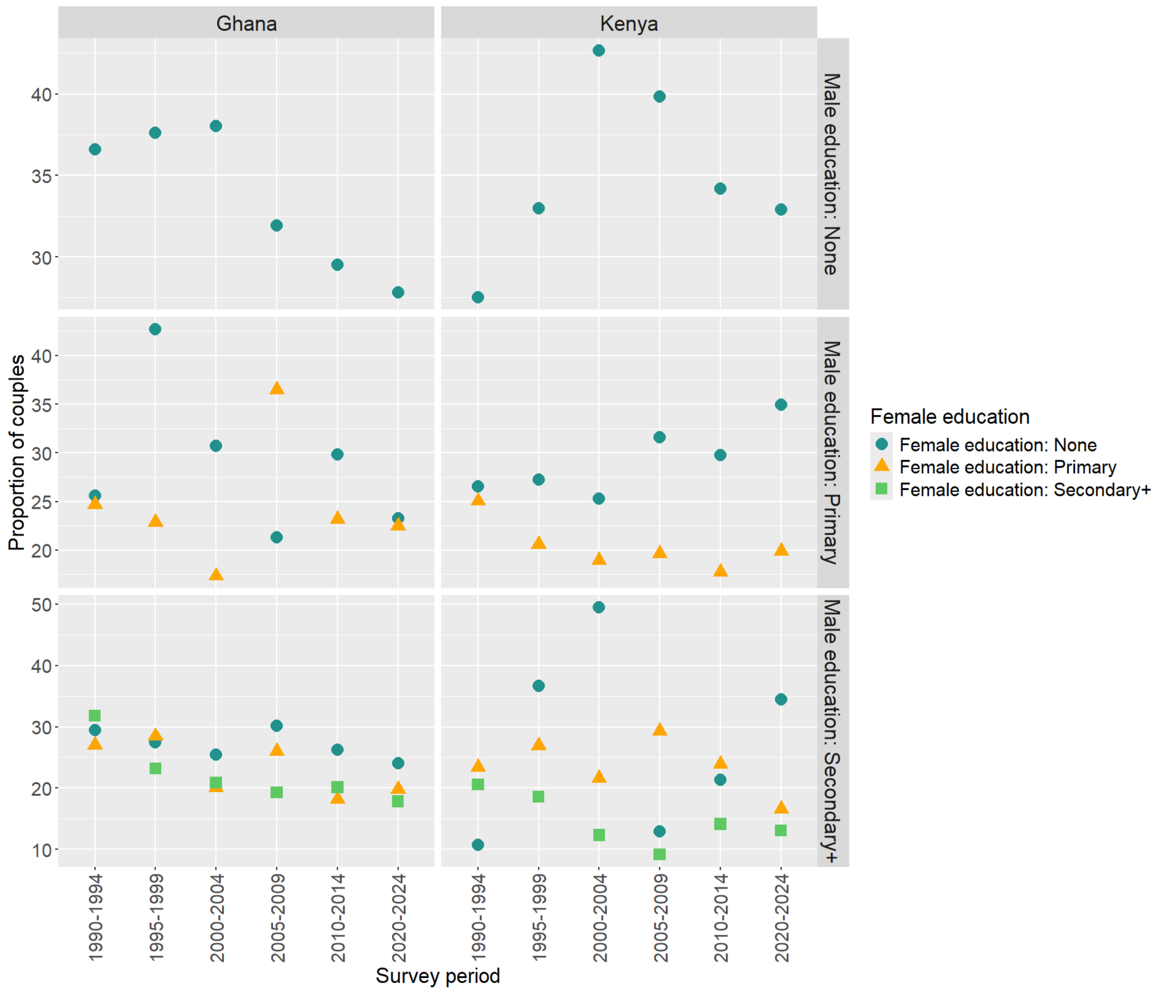


Note: Data are presented separately for men and women; not couple-level dyads.

In both countries, the proportion of couples for female education is lower than for male education. The proportion of high-age-gap couples by education levels is overall considerably lower in Kenya than in Ghana. In Ghana, the high-age-gap-couple proportion is declining by most levels of education; however, by male education, there is a sharper decline among men with no education than other groups. Meanwhile, in Kenya, there is a slight increase in the high-age-gap-couple proportion by male and female education level "no education", while the proportions are declining for all other education levels.

Figure 7 displays the proportion of couples with a high age gap by the couple's education levels. The figure shows the proportion by the male partner's level of education and the points representing their corresponding spouse's education level.

Figure 7: Proportion of couples currently in a high age gap union by country and joint educational combinations



Note: Data are presented for couple-level dyads.

Overall, men with secondary and higher education have the lowest proportions of high age gap partnerships, followed by men with primary education, then those without education. However, there are different emerging trends by the couples' joint educational combinations. While in Kenya, the trend of high-age-gap couples for men with primary education is increasing with women with no education, there is a decline in the trend for partnerships with primary-educated women. Meanwhile, the trend in the high-age-gap couple proportions is decreasing among couples with no education in Ghana.

4.4 Absolute and percentage changes in age gap quantities

Table 2 presents the percentage changes in mean spousal age gap and high-age-gap couples' proportions in Ghana and Kenya. These figures follow the results of Equation 1. Both Kenya and Ghana experienced declines in spousal age gaps. In Ghana, the mean spousal age gap fell by about 21% between 1990-1994 and 2020-2024, while the proportion of couples with high age gaps dropped by around 30%. Kenya followed a similar trend, reducing the mean spousal age gap from 1990-1994 to 2020-2024 by 22% and the proportions of couples with high age gaps by 28%. These declines indicate that changes in education and partner preferences were consistent across both countries. Although both countries experienced significant reductions in the mean spousal age gap and higher age gap proportions, Ghana had more declines in the proportions of couples with high age gaps than Kenya.

Table 2: Percentage change in mean spousal and high age gap proportion.

Country	Estimate	1990-1994	2020-2024	Absolute change	Percentage change
Ghana	Mean spousal gap	7.18	5.67	-1.51	-21.03%
	High gap proportion	29.41%	20.6%	-8.81%	-29.96%
Kenya	Mean spousal gap	6.89	5.34	-1.55	-22.49%
	High gap proportion	24.21%	17.39%	-6.82%	-28.17%

The study adopts three strategies to determine the role of education: focus on male education, female education and couples' joint educational combinations. Table 3 presents the percentage change of the mean spousal age gap and the proportion of couples with a higher age gap by the different levels of education.

Table 3: Absolute and percentage changes in estimates by different education levels.

Country	Sex	Female education	Male education	M_{t_0}	M_{t_1}	ΔM	$\%\Delta M$	$P_{\geq 10 t_0}$	$P_{\geq 10 t_1}$	$\Delta P_{\geq 10}$	$\%\Delta P_{\geq 10}$
Ghana	Female	None		7.47	6.33	-1.14	-15.30	32.70	26.03	-6.67	-20.39
		Primary		6.90	6.07	-0.83	-12.02	25.33	20.46	-4.87	-19.23
		Secondary+		6.59	5.22	-1.37	-20.77	31.82	17.81	-14.01	-44.03
	Male	None		8.22	6.74	-1.48	-17.97	36.59	27.81	-8.77	-23.98
		Primary		6.49	6.12	-0.37	-5.65	25.00	22.93	-2.07	-8.27
		Secondary+		7.16	5.39	-1.77	-24.73	28.43	18.80	-9.63	-33.88
	Couple	None	None	8.22	6.74	-1.48	-17.97	36.59	27.81	-8.77	-23.98
		None	Primary	6.07	5.95	-0.12	-1.96	25.61	23.26	-2.35	-9.19
		Primary	Primary	6.70	6.35	-0.35	-5.26	24.69	22.51	-2.18	-8.84
		None	Secondary+	6.94	5.72	-1.23	-17.66	29.41	24.07	-5.34	-18.16
		Primary	Secondary+	7.41	5.99	-1.43	-19.25	26.98	19.82	-7.16	-26.55
		Secondary+	Secondary+	6.59	5.22	-1.37	-20.77	31.82	17.81	-14.01	-44.03
Kenya	Female	None		6.81	7.53	0.72	10.63	26.00	33.88	7.88	30.31
		Primary		7.10	5.72	-1.38	-19.44	24.52	18.88	-5.64	-23.01
		Secondary+		6.28	4.56	-1.73	-27.47	20.59	13.08	-7.51	-36.46
	Male	None		7.00	7.85	0.84	12.02	27.52	32.89	5.36	19.49

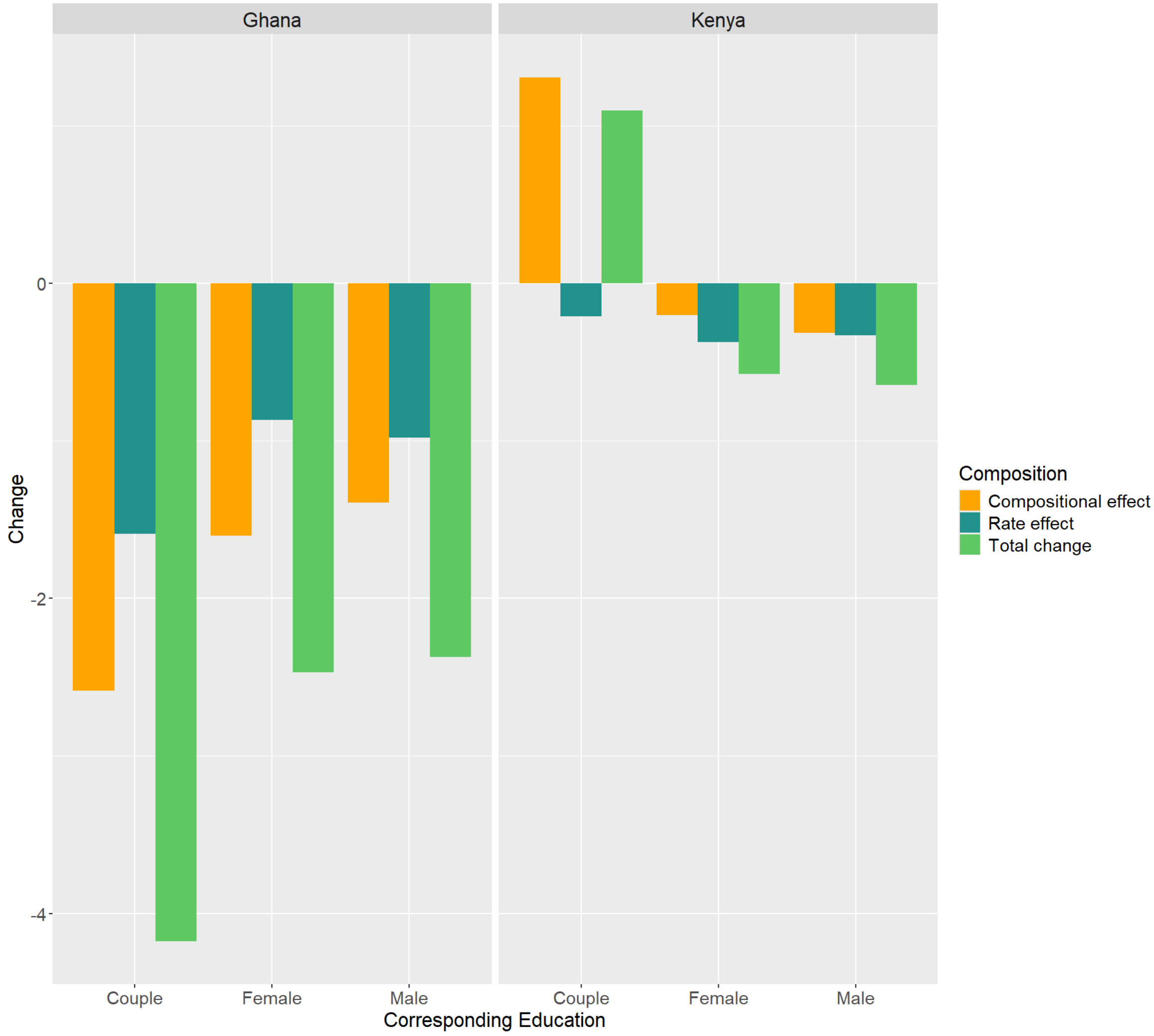
	Primary		6.93	5.94	-0.98	-14.17	25.46	20.97	-4.49	-17.62
	Secondary+		6.81	4.83	-1.98	-29.10	21.63	14.30	-7.33	-33.90
Couple	None	None	7.00	7.85	0.84	12.02	27.52	32.89	5.36	19.49
	None	Primary	6.81	7.33	0.52	7.65	26.53	34.96	8.43	31.78
	Primary	Primary	6.97	5.84	-1.13	-16.24	25.05	19.91	-5.14	-20.52
	None	Secondary+	5.60	6.94	1.34	24.01	10.71	34.45	23.74	221.69
	Primary	Secondary+	7.38	5.46	-1.92	-25.99	23.39	16.57	-6.82	-29.15
	Secondary+	Secondary+	6.28	4.56	-1.73	-27.47	20.59	13.08	-7.51	-36.46

In Ghana, the mean spousal age gap and proportion of couples with a high age gap declined across the different levels of education. On average, declines in the mean spousal age gap were more pronounced by male education than female education in both Ghana and Kenya. However, overall, there were more reductions in age gap proportions by female education than compared to male education. While in Kenya, other education groups experienced declines in mean spousal age gap and high age gap proportion; it was men and women with no education who experienced increases in these measures. The proportion of high-age-gap couples where men had secondary and higher education, yet their spouses had no education, more than doubled by the last survey period. However, in Ghana and Kenya, male and female education "secondary+" and couples both with secondary and higher education, experienced the most declines in mean spousal age gap and high age gap proportions.

4.5 Decomposition of spousal age differences

This study assesses the role of changes in the proportion of couples with high age gaps by levels of education to shifts in the mean spousal age gap. The study applies the formula in Equation 2 to mean spousal age gap, focusing on male education, female education and couples' joint educational combinations. Figure 8 and Table 4 illustrate that the drivers of spousal age gap reduction differ between Ghana and Kenya.

Figure 8: Decomposition results by education levels, Ghana and Kenya.



In Kenya, behavioural changes within educational groups account for a larger share of the decline, meaning that partner selection patterns have shifted toward smaller age gaps. This suggests that in Kenya, education not only expanded but also actively changed social norms around age disparity in marriage. In Ghana, structural changes, particularly increasing male education levels, appear to be associated with the decline in spousal age gaps. In other words, Ghana's age gap decline is mainly due to more men becoming educated, while in Kenya's case, it is mostly due to men changing their preferences regardless of education level. This key distinction highlights why policy approaches in each country may need to differ.

Table 4: Components of decomposition by education levels.

Country	Education by	Male education	Female education	Structural effect	Rate effect
Ghana	Couple	None	None	-0.66	-0.48
		Primary	None	-0.14	-0.03
			Primary	-0.14	-0.08
		Secondary+	None	-0.34	-0.33
			Primary	-0.48	-0.33
			Secondary+	-0.83	-0.34
			Total	**-2.59**	**-1.59**
	Male	None		-0.66	-0.48
		Primary		-0.13	-0.09
		Secondary+		-0.60	-0.42
			Total	**-1.39**	**-0.982**
	Female		None	-0.46	-0.34
			Primary	-0.32	-0.19
			Secondary+	-0.83	-0.34
			Total	**-1.60**	**-0.865**
Kenya	Couple	None	None	0.40	0.25
		Primary	None	0.60	0.16
			Primary	-0.33	-0.25
		Secondary+	None	1.49	0.30
			Primary	-0.44	-0.38
			Secondary+	-0.41	-0.29
			Total	**1.31**	**-0.211**
	Male	None		0.40	0.25
		Primary		-0.29	-0.23
		Secondary+		-0.43	-0.36
			Total	**-0.317**	**-0.329**
	Female		None	0.57	0.22
			Primary	-0.36	-0.30
			Secondary+	-0.41	-0.29
			Total	**-0.203**	**-0.373**

Altogether, the changes in the proportion of couples with high age gaps contributed to reductions in mean spousal age gaps across sub-regions and by the different partner's level of education. In Kenya, for males and females, and also couples with no education, the contributions by behavioural and compositional changes were positive, which led to increases in the spousal age gap. Meanwhile, in Ghana, for the same groups, the contributions of both structural changes and behavioural changes led to reductions in mean spousal age gaps. While in Ghana the changes in the proportion of couples with high age gap (structural effect) led to considerable reductions in mean spousal age gap than the behaviours of the couples (rate effect), in Kenya, aside from the couple's education levels, the reductions in the mean spousal age gaps were primarily due to changes in the behaviour of males and females.

5. Discussion and conclusion

This study focuses on spousal age gaps with an interest in high-age-gap couples in Ghana and Kenya to fill an under-explored but pivotal gap in the literature. These patterns matter in how they reshape women's bargaining power, reproductive autonomy, and the broader conditions for gender-equitable unions (Magali and Veronique 2005; Feng and Ren 2022). The study finds that reductions in the spousal age gap and the proportion of couples with a high age gap differ between Ghana and Kenya. This section discusses the key findings in light of the three central research questions: decline of spousal age gaps over time, to what extent are these changes compositional versus behavioural, and the role of male and female education levels in driving these shifts. Our results indicate that while educational expansion plays a major role, broader factors such as the decline in educational hypergamy and the reduced prevalence of polygynous unions may also underlie the observed narrowing of spousal age gaps. These mechanisms, though not fully captured in our analysis, align with fertility transition theory and the growing evidence of changing partner selection norms in sub-Saharan Africa (Kyei et al. 2025).

Consistent with Hertrich (2017), our findings show that Ghana experienced overall higher mean spousal age gaps than Kenya. Kenya's spousal age gap was already lower at the start, implying that further reductions depended more on shifting social norms rather than educational expansion alone. This contrast suggests that education-focused policies may be more effective in Ghana, while in Kenya, initiatives targeting partner selection norms, such as gender-equitable messaging in educational settings or professional environments, may be helpful in further reducing spousal age gaps. However, these are proposed mechanisms on the drivers of these changes and other study designs, outside the scope of this study, could validate these mechanisms. In addition, the proportion of men and women with secondary and higher education levels, with a partner age gap of more than ten years, is generally lower than other educational groups across both countries. Furthermore, there is a more significant proportion of couples with a high age gap (ten years or more) in Ghana than in Kenya. Similarly, across levels of education, by male and female education and couples' joint educational combinations, individuals with secondary+ education experienced the lowest mean spousal age gaps in Ghana and Kenya.

The study decomposes the mean spousal age gap across two survey periods 2020-2024 and 1990-1994, by education level to examine the role of education and the proportion of couples with a high age gap to changes in the spousal age gap in Ghana and Kenya. These periods cover the introduction and implementation periods of educational reforms from the 1980s to the late 2000s, encompassing multiple variations of the UPE. The observed increase in secondary+ education attainment, particularly among men in Ghana, aligns with the long-term effects of the UPE reforms implemented in the early 2000s. These reforms likely contributed to both compositional and behavioural shifts observed in our decomposition analysis. In Ghana, declines were structurally driven, as increased male educational attainment shifted the overall composition of marriage-age men. In Kenya, however, changes were primarily behavioural, reflecting evolving partner selection norms rather than just rising education levels.

These results may be associated with the notion that in Ghana, most of the changes were because more people became educated, thus choosing similarly-aged partners, whereas in Kenya, people within the same education groups overall chose partners within close proximity in age. The structural changes imply that behavioural shifts in Kenya are not solely a result of education but also broader societal transformations. Additionally, continued urbanisation and shifting economic structures may play an indirect role in reinforcing these trends. The behavioural shifts in Kenya may stem from broader exposure to mass media, evolving gender norms, urbanisation, and increased interaction in educational and professional environments. These shifts likely affect perceptions of ideal partner characteristics and reduce preferences for large age gaps (Bongaarts 2017). Beyond urbanisation, shifting cultural norms regarding marriage timing and partner selection may also contribute to Kenya's behavioural changes. Increased exposure to globalised media, economic empowerment of women, and legal reforms promoting gender equity in marriage may have reinforced declining preferences for large spousal age gaps (Kyei and Bawah 2024; Iacoella, Gassmann, and Tirivayi 2022; Schoumaker 2019). These findings suggest that both educational expansion and shifts in partner preferences may contribute to narrowing spousal age gaps. However, our descriptive analysis cannot establish causality, and any policy implications should be interpreted cautiously and in conjunction with broader societal factors.

Recent studies suggest a decline in hypergamous marriages as gender gaps in education narrow, leading to more age-similar partnerships (Esteve et al. 2016; Lin, Desai, and Chen 2020). The findings in Kenya align with this broader trend, indicating that behavioural shifts in partner selection may be linked to declining societal preferences for significant spousal age differences (Amoo 2020). In Ghana, the starting levels of spousal age gaps were higher, meaning any shift in education distribution could lead to larger reductions. Unlike Kenya, where behavioural shifts contributed significantly to spousal age gap declines, Ghana's reductions were primarily structural. This may be due to the stronger persistence of traditional marriage customs, where older male spouses remain socially preferred despite rising education levels. Additionally, as more Ghanaian men attain higher education, they may encounter partners similar in age in urban and professional settings, leading to a gradual decline in hypergamous marriages. In contrast, Kenya's lower initial spousal age gaps meant less room for drastic structural shifts, making behavioural changes (e.g., shifting partner preferences) the primary driver of declines. Beyond education, concurrent changes such as urbanisation, globalisation, increased access to contraceptives, and gender-equitable messaging in schools and workplaces likely shaped marriage dynamics. These factors may interact with educational expansion to accelerate reductions in spousal age gaps.

While the study provides valuable insights into the role of education in changing the spousal age gap among couples in Ghana and Kenya, it has limitations. The limitation that arises in the methodology is that the Kitagawa decomposition does not permit a more complex analysis of other factors that could influence the spousal age gap, such as religion or the type of marital union, whether polygamy or monogamy. Furthermore, the study does not distinguish between monogamous and polygynous unions, which are known to be associated with larger spousal age gaps. However, these determinants were outside the scope of this study. The study aimed at looking at all spousal connections and not particularly focusing on union types. Despite the limitations, the study offered some understanding of the role of education in reducing spousal age gaps in Ghana and Kenya. The results of this study contribute to the slow but growing research on determinants of fertility with an emphasis on males in sub-Saharan Africa, highlighting the need to involve men in sub-Saharan Africa in matters concerning fertility (Batyra, Kohler, and Furstenberg 2021; Schoumaker 2017).

Although educational hypergamy is discussed conceptually, the data is not conducive for a direct analysis of shifting hypergamy trends due to limited sample sizes in some joint education categories as seen in Figure A1. Future research may explore this in greater depth. Because polygynous unions typically involve older husbands, their inclusion likely inflates observed spousal age gaps. Distinguishing polygynous from monogamous unions in future work would provide clearer evidence of their specific contribution. Furthermore, estimates for highly educated women in earlier survey periods are based on very small samples, as seen in Appendix A1. These small cell sizes may reduce the robustness of decomposition results and limit our ability to fully examine hypergamous patterns. In addition, this analysis does not distinguish between first and higher-order unions, nor does it account for age at union formation, divorce, or remarriage. These factors could influence spousal age gaps, particularly in contexts where widowed or divorced women enter new unions with significantly older or younger partners, or where polygynous unions are more common. Future research with richer union histories could offer deeper insights into how these dynamics shape age differences within marriages.

Given the findings, policies should be tailored to country-specific dynamics. In Ghana, where structural shifts drive declines, expanding access to secondary and higher education, particularly in rural areas, may contribute to further reductions in high spousal age gaps. However, the persistence of significant age disparities suggests that deeply rooted social norms around marriage timing and partner selection may also need to be addressed. In addition, urban migration may lead to increased exposure to age-similar peers in educational and professional settings, which may weaken traditional norms favouring large spousal age gaps (Menashe-Oren and Sánchez-Páez 2023). Urban environments also facilitate later marriages by extending schooling and delaying economic stability, both of which influence partner selection (Goujon, Lutz, and Kc 2015; Kramer 2020).

These findings highlight the role of male education in reshaping marital patterns and reducing extreme spousal age gaps. While education plays a major role in spousal age gap changes, additional factors, such as shifting economic conditions and marriage law reforms, may further contribute, particularly in Kenya. Although cases where women were more educated than their male partners were excluded in this study, trends point out that such unions are increasing over time (Esteve et al. 2016). While the findings in this study are not causal, they highlight potential pathways through which education and broader social change intersect to influence marital dynamics. Future studies with larger datasets could examine whether these partnerships influence spousal age gaps differently than traditional hypergamous unions.

References

Abbani, A.Y., Yinusa, R.A., Niazi, H., Usman, M.G., and Idris, U.B. (2024). Sociodemographic and contextual determinants of men's fertility desires in northern nigeria: An analysis of the 2018 demographic and health survey. *Journal of Population and Social Studies [JPSS]* 32: 829–846.

Adebowale, A.S. (2018). Spousal age difference and associated predictors of intimate partner violence in nigeria. *BMC Public health* 18: 1–15.

Adhikari, S., Lutz, W., and Kebede, E. (2024). Forecasting africa's fertility decline by female education groups. *Proceedings of the National Academy of Sciences* 121(46): e2320247121.

Adu Boahen, E. (2024). The effect of female secondary education on fertility and the timing of birth: regression discontinuity evidence from ghana. *Journal of Social and Economic Development* 1–21.

Adu Boahen, E. and Yamauchi, C. (2018). The effect of female education on adolescent fertility and early marriage: evidence from free compulsory universal basic education in ghana. *Journal of African Economies* 27(2): 227–248.

Amoo, E.O. (2020). Family formation in africa: Trends in age at marriage, union types, patterns and determinants. *Family demography and post-2015 development agenda in Africa* 99–125.

Ausubel, J., Kramer, S., Shi, A.F., and Hackett, C. (2022). Measuring age differences among different-sex couples: Across religions and 130 countries, men are older than their female partners. *Population Studies* 76(3): 465–476.

Babalola, J.B. (2013). Lessons from post-independence education reforms in africa.

Bado, A.R., Guengant, J.P., and Maga, H.I. (2022). Sub-saharan africa: Slow fertility transitions despite policy efforts. In: *International handbook of population policies*. Springer: 159–182.

Batyra, E., Kohler, H.P., and Furstenberg, F.F. (2021). Changing gender gaps in the timing of first union formation and sexual initiation in sub-saharan africa. *Population and Development Review* 47(2): 289–322.

Batyra, E., Pesando, L.M., Castro Torres, A.F., Furstenberg, F.F., and Kohler, H.P. (2023). Union formation, within-couple dynamics, and child well-being: A global macrolevel perspective. *Population, space and place* 29(5): e2661.

Beaujouan, É., Zeman, K., and Nathan, M. (2023). Delayed first births and completed fertility across the 1940–1969 birth cohorts. *Demographic Research* 48: 387–420.

Bongaarts, J. (2010). The causes of educational differences in fertility in sub-saharan africa. *Vienna yearbook of population research* 31–50.

Bongaarts, J. (2017). Africa's unique fertility transition. *Population and Development Review* 43: 39–58.

Bongaarts, J. and Blanc, A.K. (2015). Estimating the current mean age of mothers at the birth of their first child from household surveys. *Population health metrics* 13: 1–6.

Bongaarts, J., Mensch, B.S., and Blanc, A.K. (2017). Trends in the age at reproductive transitions in the developing world: The role of education. *Population studies* 71(2): 139–154.

Carmichael, S. (2011). Marriage and power: Age at first marriage and spousal age gap in lesser developed countries. *The History of the Family* 16(4): 416–436.

Chae, S. and Agadjanian, V. (2022). The transformation of polygyny in sub-saharan africa. *Population and development review* 48(4): 1125–1162.

Church, A.C., Ibitoye, M., Chettri, S., and Casterline, J.B. (2023). Traditional supports and contemporary disrupters of high fertility desires in sub-saharan africa: a scoping review. *Reproductive Health* 20(1): 86.

Dudel, C., Cheng, Y.h.A., and Klüsener, S. (2023). Shifting parental age differences in high-income countries: Insights and implications. *Population and Development Review* 49(4): 879–908.

Esteve, A., García-Román, J., and Permanyer, I. (2012). The gender-gap reversal in education and its effect on union formation: the end of hypergamy? *Population and Development Review* 38(3): 535–546.

Esteve, A., Schwartz, C.R., Van Bavel, J., Permanyer, I., Klesment, M., and Garcia, J. (2016). The end of hypergamy: Global trends and implications. *Population and development review* 42(4): 615.

Feng, Y. and Ren, J. (2022). Within marriage age gap across countries. *Economics Letters* 210: 110190.

Ferré, C. (2009). Age at first child: does education delay fertility timing? the case of kenya. *The case of Kenya (February 1, 2009). World Bank Policy Research Working Paper* (4833).

Frejka, T. (2010). Cohort overlays of evolving childbearing patterns: How postponement and recuperation are reflected in period fertility trends. *Rostock: Max Planck Institute for Demographic Research (MPIDR working paper: WP-2010-026)* .

Garenne, M. (2004). Age at marriage and modernisation in sub-saharan africa. *Southern*

African Journal of Demography 9(2): 59–79.

Goujon, A. (2022). The education revolution. In: *International Handbook of Population Policies*. Springer: 665–680.

Goujon, A., Lutz, W., and Kc, S. (2015). Education stalls and subsequent stalls in african fertility: A descriptive overview. *Demographic Research* 33: 1281–1296.

Gustafson, P. and Fransson, U. (2015). Age differences between spouses: Sociodemographic variation and selection. *Marriage & Family Review* 51(7): 610–632.

Hertrich, V. (2017). Trends in age at marriage and the onset of fertility transition in sub-saharan africa. *Population and Development Review* 43: 112–137.

Iacoella, F., Gassmann, F., and Tirivayi, N. (2022). Which communication technology is effective for promoting reproductive health? television, radio, and mobile phones in sub-saharan africa. *PLoS One* 17(8): e0272501.

Keldal, G. and Şeker, G. (2022). Marriage or career? young adults' priorities in their life plans. *The American Journal of Family Therapy* 50(5): 459–474.

Kitagawa, E.M. (1955). Components of a difference between two rates. *Journal of the american statistical association* 50(272): 1168–1194.

Kramer, S. (2020). Polygamy is rare around the world and mostly confined to a few regions. *Pew Research Center* .

Kravdal, Ø. (2001). The importance of education for fertility in sub-saharan africa is substantially underestimated when community effects are ignored. *Memorandum fra Økonomisk institutt, Universitetet i Oslo http://urn. nb. no/URN: NBN: no-7118* .

Kravdal, Ø. (2002). Education and fertility in sub-saharan africa: Individual and community effects. *Demography* 39: 233–250.

Kyei, P.S., Agyei-Mensah, S., Casterline, J.B., and Bawah, A.A. (2025). Trends in spousal age difference at first marriage in sub-saharan africa. *Journal of Biosocial Science* 1–17.

Kyei, P.S. and Bawah, A.A. (2024). Spousal age differences and women's contraceptive use in sub-saharan africa. *Contraception and Reproductive Medicine* 9(1): 45.

Lawson, D.W., Schaffnit, S.B., Hassan, A., and Urassa, M. (2021). Shared interests or sexual conflict? spousal age gap, women's wellbeing and fertility in rural tanzania. *Evolution and Human Behavior* 42(2): 165–175.

Lee, R. (2002). The demographic transition: three centuries of fundamental change. *Journal of economic perspectives* 17(4): 167–190.

Lehmiller, J.J. and Christopher, R.A. (2008). Commitment in age-gap heterosexual romantic relationships: A test of evolutionary and socio-cultural predictions. *Psychology of Women Quarterly* 32(1): 74–82.

Lesthaeghe, R. (2014). The second demographic transition: A concise overview of its development. *Proceedings of the National Academy of Sciences* 111(51): 18112–18115.

Lin, Z., Desai, S., and Chen, F. (2020). The emergence of educational hypogamy in india. *Demography* 57(4): 1215–1240.

Lumley, T. (2020). survey: analysis of complex survey samples. R package version 4.0.

Magali, B. and Veronique, H. (2005). Age difference between spouses and contraceptive practice in sub-saharan africa. *Population* 60(5-6): 725–764.

Mansour, H. and McKinnish, T. (2014). Who marries differently aged spouses? ability, education, occupation, earnings, and appearance. *Review of Economics and Statistics* 96(3): 577–580.

Marini, M.M. (1978). The transition to adulthood: Sex differences in educational attainment and age at marriage. *American sociological review* 483–507.

Menashe-Oren, A. and Sánchez-Páez, D.A. (2023). Male fertility and internal migration in rural and urban sub-saharan africa. *European Journal of Population* 39(1): 10.

Mensch, B.S., Singh, S., and Casterline, J.B. (2005). Trends in the timing of first marriage among men and women in the developing world. *The changing transitions to adulthood in developing countries: Selected studies* 118–171.

Mignot, J.F. (2010). L'écart d'âge entre conjoints. *Revue française de sociologie* 51(2): 281–320.

Mooyaart, J.E., Liefbroer, A.C., and Billari, F.C. (2022). The changing relationship between socio-economic background and family formation in four european countries. *Population Studies* 76(2): 235–251.

Musick, K., Brand, J.E., and Davis, D. (2012). Variation in the relationship between education and marriage: Marriage market mismatch? *Journal of Marriage and Family* 74(1): 53–69.

Nishimura, M., Ogawa, K., Sifuna, D., Chimombo, J., Kunje, D., Ampiah, J., Byamugisha, A., Sawamura, N., and Yamada, S. (2009). A comparative analysis of universal primary education policy in ghana, kenya, malawi and uganda. *Journal of International Cooperation in Education* 12(1): 143–158.

Qian, Y. (2017). Gender asymmetry in educational and income assortative marriage. *Journal of Marriage and Family* 79(2): 318–336.

Qian, Y. and Qian, Z. (2017). Assortative mating by education and hukou in shanghai. *Chinese Sociological Review* 49(3): 239–262.

Quisumbing, A.R. and Hallman, K. (2005). Marriage in transition: Evidence on age, education, and assets from six developing countries. *The changing transitions to adulthood in developing countries: Selected studies* 200–269.

Samuelsson, J. (2020). Partner age gap and child health in sub-saharan africa.

Schoumaker, B. (2014). *Quality and consistency of DHS fertility estimates, 1990 to 2012*. ICF International Rockville, Maryland.

Schoumaker, B. (2017). African fertility changes. In: *Africa's population: In search of a demographic dividend*. Springer: 197–211.

Schoumaker, B. (2019). Male fertility around the world and over time: How different is it from female fertility? *Population and Development Review* 459–487.

Schultz, T.P. (1997). Demand for children in low income countries. *Handbook of population and family economics* 1: 349–430.

Seligson, D. and McCants, A.E. (2022). Polygamy, the commodification of women, and underdevelopment. *Social Science History* 46(1): 1–34.

Shapiro, D. and Gebreselassie, T. (2014). Marriage in sub-saharan africa: Trends, determinants, and consequences. *Population research and policy review* 33: 229–255.

Shephard, A. (2019). Marriage market dynamics, gender, and the age gap. *SSRN Electronic Journal* .

Smith-Greenaway, E. (2015). Educational attainment and adult literacy: A descriptive account of 31 sub-saharan africa countries. *Demographic Research* 33: 1015.

Tabutin, D., Schoumaker, B., Coleman, H., Dutreuilh, C., Reeve, P., Tovey, J., and van Hoorn Alkema, B. (2020). The demography of sub-saharan africa in the 21st century. *Population* 75(2): 165–286.

Tertilt, M. (2005). Polygyny, fertility, and savings. *Journal of Political Economy* 113(6): 1341–1371.

The DHS program (2023). The DHS program- data processing. URL `https://dhsprogram.com/data/data-processing.cfm#:~:text=For%20the%20DHS%20surveys%2C%20this,process%20survey%20and%20census%20data.`

United Nations (2016). *Changing patterns of marriage and unions across the world*. Tech. rep., United Nations. URL `https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/files/`

documents/2020/Jan/un_2016_factsheet2.pdf.

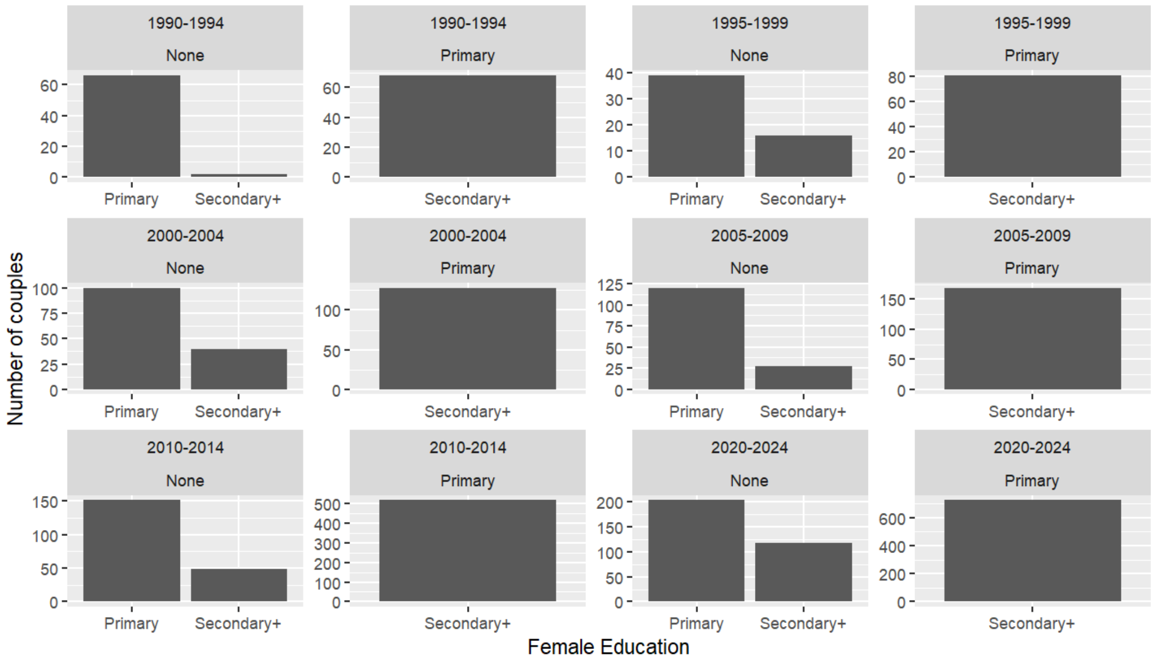
Van Zanden, J.L. (2011). The malthusian intermezzo: Women's wages and human capital formation between the late middle ages and the demographic transition of the 19th century. *The History of the Family* 16(4): 331–342.

Véronique, H. (2007). Nuptialité et rapports de genre en afrique. tendances de l'entrée en union. *Genre et sociétés en Afrique. Implications pour le développement, Paris, INED, Cahier* 160: 281–307.

Appendix

Figure A1 shows the cases excluded from the main analysis for both countries. These cases where women had a higher education than their male partners were necessary due to small sample sizes across survey periods, particularly in earlier survey waves. Including these cases would introduce instability in decomposition estimates, as fluctuations in small sample subgroups may disproportionately influence results. Therefore, we focus on the remaining dataset to ensure robust and interpretable findings. While the exclusion may marginally impact estimates, it does not change the broader trends observed in Kenya and Ghana.

Figure A1: Distribution of excluded couples



2.4. Education, religion, and male fertility in sub-Saharan Africa: A Descriptive Analysis

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Abstract: Male fertility remains under-studied in sub-Saharan Africa, particularly in terms of how education, religion, and relationship status are associated with fertility patterns. While female fertility is well-documented, male fertility trends are less understood. This study investigates how education, religious affiliation, and relationship status are related to changes in the mean number of children for men across birth cohorts in sub-Saharan Africa. The study uses a Poisson regression to find the relationship between various parameters of interest and the mean number of children ever born for males using Demographic and Health Surveys (DHS) data for 36 sub-Saharan African countries. The mean number of children changed significantly across cohorts, with men in polygamous relationships having more children than others. However, education and religion have varying effects on male fertility across countries, with relationship status playing a much stronger role. Relationship status and birth cohort play a more significant role in determining the number of children men have than the interaction between education and religion. This study expands on male fertility research by highlighting the interplay of education, religion, and relationship status on a country-specific level, emphasising the need for targeted policies.

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Descriptive Finding

Education, religion, and male fertility in sub-Saharan Africa: A descriptive analysis

Afua Durowaa-Boateng

Contents

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Descriptive Finding

Education, religion, and male fertility in sub-Saharan Africa: A descriptive analysis

Afua Durowaa-Boateng[1]

Abstract

BACKGROUND
Male fertility remains under-studied in sub-Saharan Africa, particularly in terms of how education, religion, and relationship status influence fertility patterns. While female fertility is well documented, male fertility trends are less understood.

OBJECTIVE
This study investigates how education, religious affiliation, and relationship status shape changes in the mean number of children for men across birth cohorts in sub-Saharan Africa.

METHODS
The study uses a Poisson regression to find the relationship between various parameters of interest and the mean number of children ever born for males using Demographic and Health Surveys (DHS) data for 36 sub-Saharan African countries.

RESULTS
The mean number of children changed significantly across cohorts, with men in polygamous relationships having more children than others. However, education and religion have varying effects on male fertility across countries, with relationship status playing a much stronger role.

CONCLUSION
Relationship status and birth cohort play a more significant role in determining the number of children men have than the interaction between education and religion.

CONTRIBUTION
This study expands on male fertility research by highlighting the interplay of education, religion, and relationship status on a country-specific level, emphasising the need for targeted policies.

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1. Introduction

Despite high fertility rates in sub-Saharan Africa, male fertility remains under-researched due to data limitations, with few studies exploring the role of education and religion (for example, Butame 2019; Bietsch 2015; Turner and Götmark 2023). While female fertility declines with education, male fertility patterns are more complex (Schoumaker 2019; Dudel and Klüsener 2021; Bratsberg, Kotsadam, and Walther 2021). In sub-Saharan Africa, where female fertility rates are among the highest globally, male total fertility rates (TFR) are often even higher, with countries like Niger reporting a male TFR of around 12 children per man (Schoumaker 2019). Results such as those seen in Niger appear in countries where polygamy is prevalent, given that men can father more children at a time than women, because men face fewer biological constraints on simultaneous childbearing (Schoumaker 2017). In many sub-Saharan African countries, especially in the context of polygyny and in high-fertility contexts, the fertility desires of women reflect men's desire for more children (Doepke and Tertilt 2018; Speizer and Calhoun 2022; Bankole and Audam 2011). Moreover, contraceptive use is prevalent in households where the husband is in favour across various sub-Saharan African countries (Blackstone, Nwaozuru, and Iwelunmor 2017; Nkonde, Mukanga, and Daka 2023; Demeke, Legese, and Nigussie 2024). In addition, when couples disagreed on the desired family size, men typically had a higher preference than their wives (Bankole et al. 2007; Church et al. 2023). Consequently, studying male fertility across sub-Saharan Africa could help better understand and provide a broader overview of fertility and family formation dynamics.

While the role of education in reducing female fertility is well established even in high-fertility contexts like sub-Saharan Africa (Goujon, Lutz, and KC 2015; Bongaarts 2010; Grant 2015), very few studies examine its impact on male fertility (Menashe-Oren and Sánchez-Páez 2023). Since education reduces female fertility in the region, the existing relationship may likely exist for male fertility. The mechanisms through which education reduces female fertility are extensive and well documented, ranging from years spent in school increasing the age at first birth to labour force participation, among others (Asongu et al. 2021; Lutz et al. 2018; Kim 2023; Adhikari, Lutz, and Kebede 2024). However, such extensive channels are yet to be explored for men. Furthermore, formal education, in particular, reduces the likelihood of women joining polygamous unions (Fenske 2015), a trend that may apply to men, with better-educated men potentially being less likely to engage in polygamous unions (Menashe-Oren and Sánchez-Páez 2023). Furthermore, male education has a positive relationship with contraceptive use (Bietsch 2015), potentially translating to lower fertility rates for men with higher education.

Religious beliefs shape norms on marriage, contraception, and ideal family size, which may moderate the effect of education on fertility. In more conservative religious groups, education may not lower fertility as much due to restrictions on contraception and strong pronatalist values (McQuillan 2004). Some religious groups discourage contraceptive use, while others promote delayed marriage (Choi and Hamilton 2016; Hill, Siwatu, and Robinson 2014; Kan 2024). Recent studies on female fertility, education, and religion show that the role of education in reducing fertility levels persists irrespective of religious affiliation. However, there are some variations by country (Berger and Dasré 2024). Given that religious beliefs influence attitudes toward contraception, marriage, and ideal family size, it is plausible that the effect of education on fertility may vary by religious affiliation. These factors may moderate how education affects fertility, with more religious groups potentially resisting fertility reductions associated with schooling.

This study contributes to the literature by examining male fertility patterns by education, relationship status, and broad religious affiliations. The study focuses on changes in children ever born to men using data from the Demographic and Health Surveys (DHS) (DHS program 2023). This study investigates how education, religious affiliation, relationship status, and birth cohort shape male fertility patterns across sub-Saharan African countries. Given that polygamous men can father children at a much higher rate, this study differentiates fertility patterns by relationship status to provide a clearer picture of male fertility trends. The study employs a country-specific approach in investigating these relationships as sub-Saharan Africa presents a broad array of diversity in terms of social norms, polygyny prevalence (Chae and Agadjanian 2022), different proportions of the population by religion (Stonawski et al. 2015), and male fertility rates (Schoumaker 2017), among others. Given the wide variation in the variables of interest, pooling data could obscure key country-specific patterns in male fertility determinants.

2. Data and methods

The study uses data from 36 sub-Saharan African countries within the DHS men recode file from 1991 to 2023, including countries with only one survey (DHS program 2023). Since the interest of the study lies in children ever born, the data collected focuses only on males born between 1940 and 1979, as these groups of men should be nearing the end of their reproductive ages. Furthermore, the study excludes men who reported only one partner but recorded more than 30 children, as these values are implausible. The study classifies men's birth cohorts into 10-year groups from 1940 to 1979 for the analysis and data description. Religious affiliations are Catholic, Protestant, Universal, Jehovah's Witness (JW), Muslim, and none. The umbrella group, Protestant, joins all other Christian groups aside from Catholic and Jehovah's Witnesses, while the Universal group entails other spiritual/traditional/religious belief systems. Due to the differences in teachings and beliefs surrounding abortion and the use of contraceptives, Catholics, Jehovah's Witnesses, and Protestants are separated even though they fall under Christianity (McQuillan 2004). Since the study aims to expand knowledge on the mean number of children men have in different relationship types, the variable "relationship" reflects how many wives/partners men have. The categories are “single” (for men currently without partners), “monogamous” (men with only one wife/partner), and “polygamous” (men with two or more wives/partners). In the educational categories, following the DHS, the groupings are “none,” “primary,” and “secondary+,” which combines secondary and higher education levels. Events grouped by cohort, education, relationship, and number of children with fewer than two observations are removed from the sample, as these small events might lead to biased results, especially when calculating the means. Table 1 shows the unweighted sample used in the study by education level, religious affiliations, birth cohorts, and relationship status.

Table 1: Sample by religious affiliation, education, relationship status, and cohort

Religion	Education	Relationship	1940–1949	1950–1959	1960–1969	1970–1979	Total
Catholic	None	Monogamous	1,151	4,181	8,618	9,893	23,843
		Polygamous	729	2,217	3,571	2,516	9,033
		Single	68	256	455	501	1,280
	Primary	Monogamous	662	3,514	7,373	10,246	21,795
		Polygamous	150	706	1,148	1,063	3,067
		Single	110	402	785	1,024	2,321
	Secondary+	Monogamous	366	2,792	7,650	9,624	20,432
		Polygamous	80	559	1,081	936	2,656
		Single	32	293	797	1,395	2,517
JW	None	Monogamous	66	324	542	658	1,590
		Polygamous	18	69	97	75	259
		Single	9	37	50	53	149
	Primary	Monogamous	78	558	1,345	2,034	4,015
		Polygamous	26	132	270	228	656
		Single	10	57	118	175	360
	Secondary+	Monogamous	54	413	1,237	2,075	3,779
		Polygamous	6	46	141	179	372
		Single	4	36	91	205	336
Muslim	None	Monogamous	37	160	250	282	729
		Polygamous	24	85	114	91	314
		Single	5	23	32	21	81
	Primary	Monogamous	16	146	299	395	856
		Polygamous	12	38	74	63	187
		Single	3	17	34	54	108
	Secondary+	Monogamous	18	128	277	465	888
		Polygamous	7	31	50	35	123
		Single	1	15	35	87	138
None	None	Monogamous	6	24	70	87	187
		Polygamous	2	6	16	24	48
		Single		5	15	15	35
	Primary	Monogamous	3	29	114	168	314
		Polygamous		6	35	40	81
		Single		8	23	53	84
	Secondary+	Monogamous		49	214	423	686
		Polygamous		14	46	44	104
		Single	1	9	54	105	169
Protestant	None	Monogamous	622	2,455	5,250	6,465	14,792
		Polygamous	332	1,150	2,123	1,972	5,577
		Single	58	203	381	433	1,075
	Primary	Monogamous	911	3,857	8,650	12,362	25,780
		Polygamous	204	709	1,468	1,575	3,956
		Single	137	501	964	1,349	2,951
	Secondary+	Monogamous	426	3,181	9,949	13,972	27,528
		Polygamous	82	463	1,278	1,268	3,091
		Single	48	319	1,056	1,780	3,203
Universal	None	Monogamous	222	790	1,486	1,797	4,295
		Polygamous	119	313	454	322	1,208
		Single	29	74	82	84	269
	Primary	Monogamous	110	487	1,213	1,830	3,640
		Polygamous	27	127	241	230	625
		Single	15	59	122	142	338
	Secondary+	Monogamous	57	368	1,030	1,554	3,009
		Polygamous	17	54	116	112	299
		Single	5	43	107	208	363
Total			**7,175**	**32,538**	**73,091**	**92,787**	**205,591**

Table 2 shows the unweighted sample by each country.

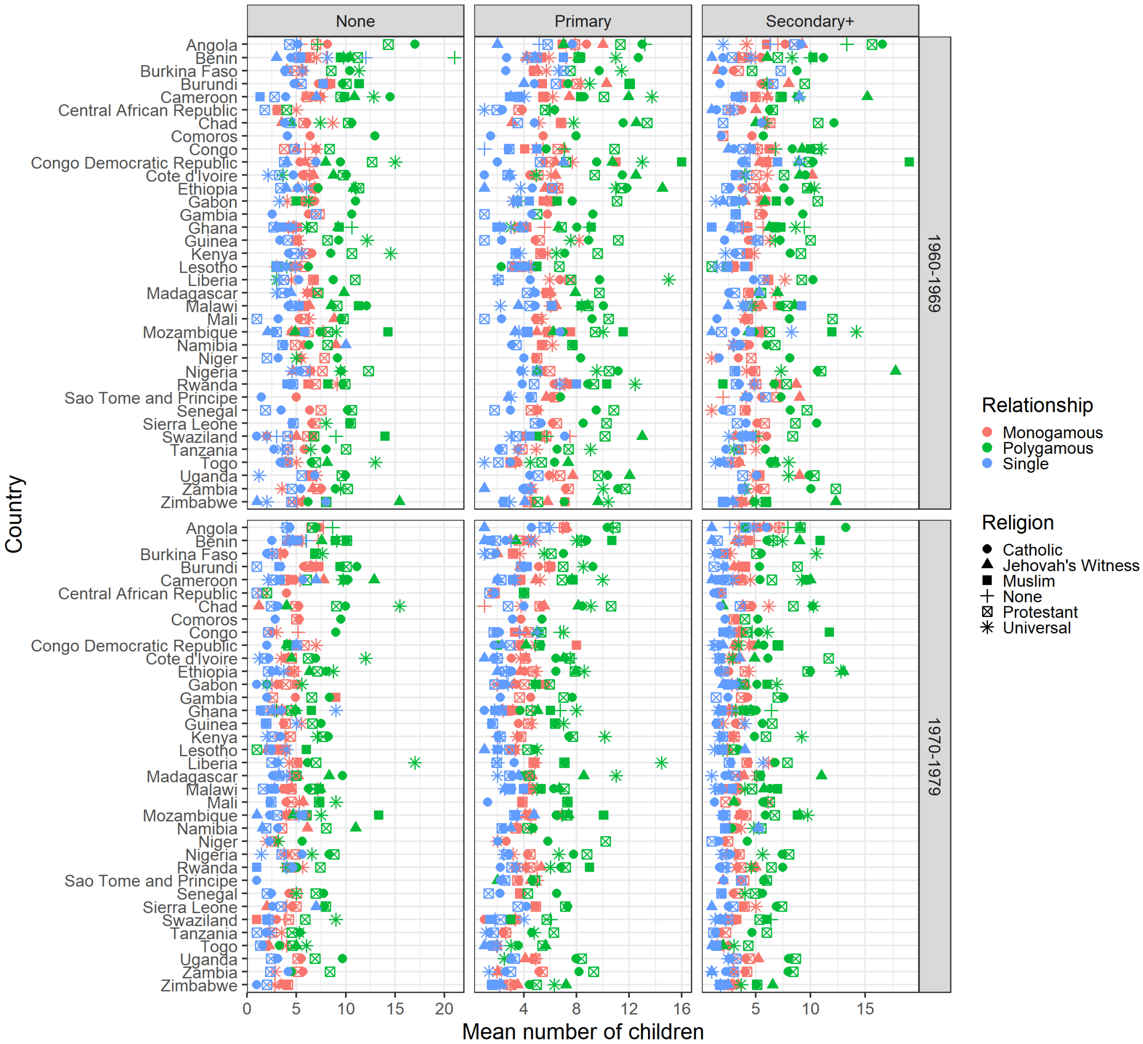
Table 2: Sample by country

Country	N (unweighted)
Angola	2,914
Benin	4,417
Burkina Faso	4,812
Burundi	3,851
Cameroon	8,417
Central African Republic	991
Chad	4,093
Comoros	774
Congo	3,024
Congo Democratic Republic	2,246
Cote d'Ivoire	2,254
Ethiopia	13,331
Gabon	3,355
Gambia	2,218
Ghana	7,058
Guinea	5,723
Kenya	9,245
Lesotho	1,833
Liberia	5,692
Madagascar	7,323
Malawi	8,379
Mali	9,244
Mozambique	5,954
Namibia	3,979
Niger	3,905
Nigeria	18,073
Rwanda	7,901
Sao Tome and Principe	975
Senegal	12,965
Sierra Leone	6,892
Swaziland	1,430
Tanzania	3,454
Togo	1,937
Uganda	4,994
Zambia	13,601
Zimbabwe	8,337
Total	**205,591**

Figures 1 and 2 show the mean number of children men have by country, religion, 10-year birth cohort, religious affiliation, and education for the 1940–1959 and 1960–1979 birth cohorts, respectively, after accounting for survey weights.

Figure 1: Mean number of children by relationship, religion, and education, 1940 to 1959

Figure 2: Mean number of children by relationship, religion, and education, 1960 to 1979



In all countries, men in polygamous relationships have more children on average than single and monogamous men. Furthermore, men born between 1970 and 1979 have fewer children than other birth cohorts. Similarly, men with secondary and higher education experience fewer children ever born on average than other categories. Regarding religion, no specific religious affiliation records the highest mean number of children ever born across all countries. For this reason, the proposed model focuses on each country to explore how the interaction between religion and education influences male fertility levels, considering variations in relationship status and birth cohort.

3. Model

Since this study focuses on the mean number of children men have in sub-Saharan Africa, the first step in the analysis involved calculating the mean number of children from the sample reported in Table 1 by country, religious affiliation, relationship, education, and 10-year birth cohort considering the survey weights using the svyby function from the survey package in R statistical software (Lumley 2020). The Poisson regression is most suited for this type of analysis, given that the variable of interest, children ever born, is a count variable that does not take on negative values (Cameron and Trivedi 2013). Given the substantial heterogeneity in fertility norms, educational attainment, and religious compositions across sub-Saharan Africa, this study estimates separate models for each country to capture country-specific patterns more accurately. Aggregating countries may obscure important country-specific dynamics, particularly given the varying prevalence of polygamy, contraception access, and socioeconomic conditions (Schoumaker 2019). For example, polygamous marriage rates, which strongly influence male fertility, vary widely by country (e.g., approximately 34% in Chad vs. approximately 2% in South Africa) (Garenne 2022), making a single pooled model less appropriate. By estimating separate models, the study ensures that observed effects are not driven by a few high-fertility or low-fertility countries. The collected means undergo a simple Poisson regression performed for each country, defined as

$$\begin{aligned} log(\lambda_i) = \quad & \beta_0 + \beta_j Cohort_j + \beta_k Religion_k + \beta_l Education_l \\ & + \beta_m Relationship_m + \beta_{kl} Religion_k Education_l, \end{aligned}$$

where β_0 is the coefficient of the intercept, β_j represents the coefficients of each cohort group j, β_k corresponds to the coefficients of each religious affiliation k, β_l is the coefficient to each education group l, β_m is the coefficient to each relationship status m, and β_{kl} is the respective coefficient to the interaction between each religious affiliation k and education level l. Due to small sample sizes in some education–religion subgroups, estimates should be interpreted cautiously. Additionally, the study runs three supplementary models – one without the interaction term, one without relationship status but including the interaction, and one excluding both – to assess the relationship of men's education to their number of children. In the models without marital status, the mean number of children is collected without relationship status.

4. Results

Table 3 presents the estimated coefficients with 95% confidence intervals. The reference categories are denoted as RC, and other abbreviations are noted below the table.

Table 3: Log coefficients of Poisson regression for each country

Parameter	Variable	Angola	Benin	Burkina Faso	Burundi	Cameroon	CAR
	Intercept	2.19 [4.38–0]	2.19 [4.37–0]	2.24 [4.48–0]	2.21 [4.42–0]	2.03 [4.06–0]	2.07 [4.14–0]
Birth cohort	1940–1949	RC	RC	RC	RC	RC	RC
	1950–1959		–0.20 [–0.40–0]	–0.34 [–0.68–0]		0.11 [0.22–0]	–0.17 [–0.34–0]
	1960–1969		–0.42 [–0.84–0]	–0.50 [–1–0]	–0.16 [–0.31–0]	–0.12 [–0.24–0]	–0.81 [–1.62–0]
	1970–1979	–0.27 [–0.55–0]	–0.69 [–1.37–0]	–1.01 [–2.02–0]	–0.42 [–0.85–0]	–0.37 [–0.74–0]	–1.22 [–2.45–0]
Religion	Catholic	RC	RC	RC	RC	RC	RC
	Protestant	–0.14 [–0.28–0]	0.03 [0.06–0]	–0.11 [–0.22–0]	–0.08 [–0.16–0]	–0.25 [–0.49–0]	–0.27 [–0.55–0]
	JW	–0.37 [–0.74–0]	–0.17 [–0.34–0]	–0.25 [–0.5–0]	–0.18 [–0.37–0]	0.24 [0.49–0]	–0.09 [–0.18–0]
	Muslim	–0.71 [–1.42–0]	0 [0-0]		–0.02 [–0.03–0]	–0.19 [–0.38–0]	
	Universal	–0.77 [–1.55–0]	0.06 [0.12–0]	0.06 [0.12–0]	0.03 [0.07–0]	–0.13 [–0.27–0]	0.35 [0.69–0]
	None	–0.26 [–0.51–0]	0.49 [0.98–0]				
Education	None	RC	RC	RC	RC	RC	RC
	Primary	0.05 [0.10–0]	0.14 [0.27–0]	–0.16 [–0.32–0]	–0.07 [–0.15–0]	–0.23 [–0.46–0]	–0.05 [–0.10–0]
	Secondary+	0.18 [0.36–0]	0.01 [0.02–0]	–0.22 [–0.44–0]	–0.55 [–1.10–0]	–0.30 [–0.59–0]	0.21 [0.41–0]
Religion: Education	Catholic: None	RC	RC	RC	RC	RC	RC
	Catholic: Primary	RC	RC	RC	RC	RC	RC
	Catholic: Secondary+	RC	RC	RC	RC	RC	RC
	Protestant: None	RC	RC	RC	RC	RC	RC
	Protestant: Primary	0.08 [0.16–0]	–0.27 [–0.54–0]	0.12 [0.24–0]	0.27 [0.54–0]	0.28 [0.56–0]	0.24 [0.49–0]
	Protestant: Secondary+	0.03 [0.07–0]	–0.31 [–0.62–0]	0.10 [0.19–0]	0.47 [0.94–0]	0.24 [0.48–0]	0.03 [0.06–0]
	JW: None	RC	RC	RC	RC	RC	RC
	JW: Primary	–0.04 [–0.09–0]	–0.10 [–0.20–0]	0.15 [0.29–0]	0.39 [0.79–0]	0.05 [0.10–0]	0.32 [0.64–0]
	JW: Secondary+		–0.05 [–0.10–0]	–0.84 [–1.68–0]	0.51 [1.02–0]	–0.05 [–0.10–0]	
	Muslim: None	RC	RC	RC	RC	RC	RC
	Muslim: Primary	0.41 [0.81–0]	–0.25 [–0.50–0]		0.09 [0.17–0]	0.24 [0.49–0]	
	Muslim: Secondary+		–0.16 [–0.31–0]		0.17 [0.33–0]	0.25 [0.50–0]	
	Universal: None	RC	RC	RC	RC	RC	RC
	Universal: Primary	0.78 [1.57–0]	–0.18 [–0.36–0]	0.13 [0.25–0]	–0.08 [–0.15–0]	0.08 [0.17–0]	–0.34 [–0.69–0]
	Universal: Secondary+		–0.36 [–0.72–0]	0.32 [0.65–0]	–0.09 [–0.17–0]	0.11 [0.23–0]	–0.43 [–0.85–0]
	None: None	RC	RC	RC	RC	RC	RC
	None: Primary	0.21 [0.42–0]	–0.58 [–1.16–0]				
	None: Secondary+	–0.02 [–0.05–0]	–0.58 [–1.15–0]				
Relationship status	Monogamous	RC	RC	RC	RC	RC	RC
	Single	–0.41 [–0.82–0]	–0.26 [–0.52–0]	–0.20 [–0.41–0]	–0.38 [–0.77–0]	–0.38 [–0.75–0]	–0.67 [–1.34–0]
	Polygamous	0.38 [0.75–0]	0.59 [1.18–0]	0.57 [1.15–0]	0.33 [0.67–0]	0.60 [1.20–0]	0.53 [1.05–0]

Notes: RC – Reference category
JW – Jehovah's Witness
CAR – Central African Republic

Table 3: (Continued)

Parameter	Variable	Chad	Comoros	Congo	Congo DR	Cote d'Ivoire	Ethiopia
	Intercept	2.25 [4.50–0]	2.14 [4.28–0]	2.06 [4.12–0]	2.10 [4.20–0]	2.05 [4.10–0]	1.96 [3.93–0]
Birth cohort	1940–1949	RC	RC	RC	RC	RC	RC
	1950–1959	–0.1 [–0.21–0]		–0.25 [–0.51–0]	–0.18 [–0.37–0]	–0.07 [–0.15–0]	–0.10 [–0.2–0]
	1960–1969	–0.36 [–0.72–0]	–0.29 [–0.57–0]	–0.41 [–0.83–0]	–0.33 [–0.66–0]	–0.35 [–0.71–0]	–0.22 [–0.43–0]
	1970–1979	–0.51 [–1.02–0]	–0.49 [–0.99–0]	–0.80 [–1.60–0]	–0.97 [–1.95–0]	–0.68 [–1.37–0]	–0.49 [–0.99–0]
Religion	Catholic	RC	RC	RC	RC	RC	RC
	Protestant	–0.14 [–0.28–0]	–0.04 [–0.07–0]	–0.14 [–0.29–0]	0.09 [0.17–0]	0.06 [0.12–0]	0.18 [0.36–0]
	JW	–0.65 [–1.30–0]		–0.04 [–0.08–0]	0.04 [0.07–0]	–0.03 [–0.05–0]	0.04 [0.07–0]
	Muslim			–0.23 [–0.46–0]	0.44 [0.87–0]		
	Universal	–0.04 [–0.08–0]		0.14 [0.27–0]	0.63 [1.26–0]	–0.09 [–0.19–0]	0.12 [0.25–0]
	None	–0.47 [–0.93–0]		–0.02 [–0.04–0]			0.04 [0.09–0]
Education	None	RC	RC	RC	RC	RC	RC
	Primary	0.01 [0.02–0]	–0.21 [–0.41–0]	0.11 [0.22–0]	0 [0–0]	–0.05 [–0.11–0]	0.07 [0.15–0]
	Secondary+	–0.18 [–0.35–0]	–0.43 [–0.86–0]	–0.05 [–0.09–0]	0.08 [0.17–0]	–0.05 [–0.1–0]	–0.18 [–0.35–0]
Religion: Education	Catholic: None	RC	RC	RC	RC	RC	RC
	Catholic: Primary	RC	RC	RC	RC	RC	RC
	Catholic: Secondary+	RC	RC	RC	RC	RC	RC
	Protestant: None	RC	RC	RC	RC	RC	RC
	Protestant: Primary	0.16 [0.32–0]		0.06 [0.13–0]	–0.09 [–0.17–0]	0 [–0.01–0]	–0.25 [–0.49–0]
	Protestant: Secondary+	0.18 [0.36–0]	–0.04 [–0.07–0]	0.16 [0.31–0]	–0.04 [–0.07–0]	–0.04 [–0.08–0]	0.02 [0.03–0]
	JW: None	RC	RC	RC	RC	RC	RC
	JW: Primary	0.58 [1.15–0]		0.12 [0.24–0]	0.27 [0.54–0]	0.23 [0.46–0]	–0.28 [–0.56–0]
	JW: Secondary+	0.25 [0.51–0]		–0.06 [–0.11–0]	0.04 [0.08–0]	0.14 [0.28–0]	0.27 [0.53–0]
	Muslim: None	RC	RC	RC	RC	RC	RC
	Muslim: Primary			–0.03 [–0.06–0]	0.07 [0.14–0]		
	Muslim: Secondary+			0.37 [0.74–0]			
	Universal: None	RC	RC	RC	RC	RC	RC
	Universal: Primary	–0.16 [–0.31–0]		–0.13 [–0.25–0]	–0.26 [–0.52–0]	0.03 [0.07–0]	–0.02 [–0.05–0]
	Universal: Secondary+	–0.03 [–0.05–0]		0.02 [0.04–0]	–0.33 [–0.65–0]	0.04 [0.09–0]	0.06 [0.12–0]
	None: None	RC	RC	RC	RC	RC	RC
	None: Primary			0.16 [0.33–0]			
	None: Secondary+			0.01 [0.01–0]			
Relationship status	Monogamous	RC	RC	RC	RC	RC	RC
	Single	–0.46 [–0.91–0]	–0.59 [–1.18–0]	–0.31 [–0.62-0]	–0.35 [–0.70–0]	–0.64 [–1.28–0]	–0.31 [–0.63–0]
	Polygamous	0.53 [1.05–0]	0.43 [0.86–0]	0.50 [1–0]	0.40 [0.80–0]	0.53 [1.06–0]	0.52 [1.04–0]

Notes: RC – Reference category
JW – Jehovah's Witness

Table 3: (Continued)

Parameter	Variable	Gabon	Gambia	Ghana	Guinea	Kenya	Lesotho
	Intercept	2.12 [4.23–0]	1.9 [3.8–0]	2.05 [4.11–0]	2.14 [4.27–0]	2.2 [4.4–0]	1.65 [3.31–0]
Birth cohort	1940–1949	RC	RC	RC	RC	RC	RC
	1950–1959	0.05 [0.09–0]		–0.21 [–0.41-0]	–0.26 [–0.52-0]	–0.25 [–0.51–0]	
	1960–1969	–0.34 [–0.68–0]	–0.1 [–0.19–0]	–0.48 [–0.95–0]	–0.34 [–0.68–0]	–0.48 [–0.96–0]	–0.09 [–0.18–0]
	1970–1979	–0.71 [–1.43–0]	–0.41 [–0.82–0]	–0.83 [–1.67–0]	–0.68 [–1.36–0]	–0.79 [–1.59–0]	–0.33 [–0.66–0]
Religion	Catholic	RC	RC	RC	RC	RC	RC
	Protestant	0.17 [0.35–0]	0.07 [0.15–0]	–0.12 [–0.23–0]	–0.08 [–0.17–0]	–0.06 [–0.13–0]	–0.22 [–0.44–0]
	JW	0.02 [0.04–0]		0.09 [0.19–0]			–0.63 [–1.26–0]
	Muslim	–0.23 [–0.45–0]	0.71 [1.41–0]	0.04 [0.08–0]			0.02 [0.04–0]
	Universal	–0.29 [–0.58–0]		–0.13 [–0.26–0]	0.14 [0.29–0]	0.18 [0.35–0]	–0.05 [–0.09–0]
	None			0.2 [0.41–0]		–0.68 [–1.37–0]	
Education	None	RC	RC	RC	RC	RC	RC
	Primary	–0.15 [–0.3–0]	–0.03 [–0.06–0]	–0.42 [–0.84–0]	–0.19 [–0.39–0]	–0.03 [–0.06–0]	–0.23 [–0.45–0]
	Secondary+	–0.12 [–0.24–0]	–0.07 [–0.13–0]	–0.24 [–0.48–0]	–0.29 [–0.57–0]	–0.29 [–0.59–0]	–0.57 [–1.15–0]
Religion: Education	Catholic: None	RC	RC	RC	RC	RC	RC
	Catholic: Primary	RC	RC	RC	RC	RC	RC
	Catholic: Secondary+	RC	RC	RC	RC	RC	RC
	Protestant: None	RC	RC	RC	RC	RC	RC
	Protestant: Primary	–0.2 [–0.39–0]	–0.49 [–0.98–0]	0.35 [0.7–0]	0.19 [0.37–0]	–0.04 [–0.09–0]	0.34 [0.68–0]
	Protestant: Secondary+	–0.07 [–0.15–0]	–0.22 [–0.43–0]	0.15 [0.3–0]	0.31 [0.62–0]	0.18 [0.37–0]	0.31 [0.62–0]
	JW: None	RC	RC	RC	RC	RC	RC
	JW: Primary	–0.41 [–0.83–0]		0.3 [0.59–0]			0.05 [0.11–0]
	JW: Secondary+	–0.3 [–0.59–0]		–0.03 [–0.07–0]			1.14 [2.29–0]
	Muslim: None	RC	RC	RC	RC	RC	RC
	Muslim: Primary	0.32 [0.65–0]		0.41 [0.82–0]			0.31 [0.62–0]
	Muslim: Secondary+	0.22 [0.43–0]	–1.85 [–3.7–0]	–0.07 [–0.13–0]			0.15 [0.3–0]
	Universal: None	RC	RC	RC	RC	RC	RC
	Universal: Primary	0.27 [0.55–0]		0.21 [0.41–0]	–0.09 [–0.19–0]	–0.15 [–0.31–0]	0.22 [0.44–0]
	Universal: Secondary+	0.16 [0.32–0]		0.14 [0.28–0]	0 [0–0]	–0.18 [–0.36–0]	0.03 [0.05–0]
	None: None	RC	RC	RC	RC	RC	RC
	None: Primary			0.26 [0.53–0]			
	None: Secondary+			0.12 [0.24–0]			
Relationship status	Monogamous	RC	RC	RC	RC	RC	RC
	Single	–0.42 [–0.84–0]	–0.54 [–1.08–0]	–0.21 [–0.43–0]	–0.38 [–0.77–0]	–0.3 [–0.6–0]	–0.19 [–0.38–0]
	Polygamous	0.39 [0.77–0]	0.56 [1.11–0]	0.48 [0.97–0]	0.46 [0.92–0]	0.58 [1.16–0]	0.03 [0.06–0]

Notes: RC – Reference category
JW – Jehovah's Witness

Table 3: (Continued)

Parameter	Variable	Liberia	Madagascar	Malawi	Mali	Mozambique	Namibia
	Intercept	1.90 [3.81–0]	1.97 [3.95–0]	2.27 [4.55–0]	2.17 [4.34–0]	2.01 [4.02–0]	2.15 [4.29–0]
Birth cohort	1940–1949	RC	RC	RC	RC	RC	RC
	1950–1959		0.12 [0.23–0]	–0.28 [–0.56–0]	–0.29 [–0.58–0]	–0.16 [–0.33–0]	–0.34 [–0.67–0]
	1960–1969	–0.18 [–0.35–0]	–0.21 [–0.42–0]	–0.46 [–0.91–0]	–0.49 [–0.98–0]	–0.34 [–0.67–0]	–0.58 [–1.15–0]
	1970–1979	–0.34 [–0.68–0]	–0.44 [–0.87–0]	–0.87 [–1.74–0]	–0.73 [–1.46–0]	–0.52 [–1.04–0]	–0.91 [–1.82–0]
Religion	Catholic	RC	RC	RC	RC	RC	RC
	Protestant	–0.02 [–0.04–0]	–0.04 [–0.09–0]	–0.05 [–0.11–0]	0.01 [0.03–0]	–0.01 [–0.02–0]	–0.07 [–0.14–0]
	JW		0.05 [0.10–0]	–0.02 [–0.04–0]	0.41 [0.83–0]	–0.13 [–0.26–0]	0.59 [1.18–0]
	Muslim			–0.06 [–0.12–0]		0.29 [0.58–0]	
	Universal	–0.04 [–0.08–0]	0.02 [0.05–0]	0.04 [0.07–0]	–0.22 [–0.44–0]	0.15 [0.31–0]	0.12 [0.24–0]
	None						
Education	None	RC	RC	RC	RC	RC	RC
	Primary	–0.08 [–0.17–0]	0.03 [0.07–0]	–0.07 [–0.13–0]	–0.04 [–0.09–0]	0.05 [0.09–0]	–0.07 [–0.15–0]
	Secondary+	–0.01 [–0.02–0]	–0.46 [–0.92–0]	–0.07 [–0.13–0]	–0.27 [–0.55–0]	–0.23 [–0.45–0]	–0.18 [–0.35–0]
Religion: Education	Catholic: None	RC	RC	RC	RC	RC	RC
	Catholic: Primary	RC	RC	RC	RC	RC	RC
	Catholic: Secondary+	RC	RC	RC	RC	RC	RC
	Protestant: None	RC	RC	RC	RC	RC	RC
	Protestant: Primary	0.15 [0.29–0]	–0.18 [–0.35–0]	0.03 [0.06–0]	–0.06 [–0.12–0]	0.02 [0.04–0]	–0.02 [–0.04–0]
	Protestant: Secondary+	0.08 [0.15–0]	0.14 [0.28–0]	–0.04 [–0.09–0]	0.17 [0.34–0]	–0.01 [–0.02–0]	0.12 [0.24–0]
	JW: None	RC	RC	RC	RC	RC	RC
	JW: Primary		–0.16 [–0.32–0]	0.05 [0.09–0]		–0.03 [–0.06–0]	–0.49 [–0.97–0]
	JW: Secondary+		0.36 [0.72–0]	–0.20 [–0.40–0]	–0.61 [–1.22–0]	0.06 [0.11–0]	–0.43 [–0.86–0]
	Muslim: None	RC	RC	RC	RC	RC	RC
	Muslim: Primary			0.14 [0.28–0]		–0.07 [–0.14–0]	
	Muslim: Secondary+			0.28 [0.57–0]		0.03 [0.06–0]	
	Universal: None	RC	RC	RC	RC	RC	RC
	Universal: Primary	0.29 [0.57–0]	–0.17 [–0.35–0]	–0.09 [–0.17–0]	0.45 [0.91–0]	–0.02 [–0.05–0]	0.21 [0.43–0]
	Universal: Secondary+	0.45 [0.89–0]	0.44 [0.88–0]	–0.4 [–0.79–0]	0.61 [1.22–0]	0.34 [0.68–0]	
	None: None	RC	RC	RC	RC	RC	RC
	None: Primary						
	None: Secondary+						
Relationship status	Monogamous	RC	RC	RC	RC	RC	RC
	Single	–0.36 [–0.73–0]	–0.26 [–0.52–0]	–0.24 [–0.48–0]	–0.45 [–0.89–0]	–0.36 [–0.73–0]	–0.22 [–0.44–0]
	Polygamous	0.54 [1.07–0]	0.49 [0.99–0]	0.46 [0.92–0]	0.56 [1.11–0]	0.46 [0.92–0]	0.55 [1.09–0]

Notes: RC – Reference category
JW – Jehovah's Witness

Table 3: (Continued)

Parameter	Variable	Niger	Nigeria	Rwanda	Sao Tome and Principe	Senegal	Sierra Leone
	Intercept	2.06 [4.12–0]	2 [4–0]	2.23 [4.46–0]	2.15 [4.30–0]	2.18 [4.35–0]	2.08 [4.16–0]
Birth cohort	1940–1949	RC	RC	RC	RC	RC	RC
	1950–1959	0.07 [0.15–0]	–0.06 [–0.12–0]	–0.17 [–0.33–0]	–0.25 [–0.49–0]	–0.13 [–0.27–0]	–0.20 [–0.41–0]
	1960–1969	–0.33 [–0.65–0]	–0.25 [–0.50–0]	–0.35 [–0.71–0]	–0.54 [–1.07–0]	–0.38 [–0.75–0]	–0.27 [–0.54–0]
	1970–1979	–0.78 [–1.57–0]	–0.64 [–1.28–0]	–0.78 [–1.55–0]	–1 [–1.99–0]	–0.77 [–1.54–0]	–0.57 [–1.13–0]
Religion	Catholic	RC	RC	RC	RC	RC	RC
	Protestant	0.06 [0.11–0]	0.20 [0.40–0]	0.03 [0.05–0]	–0.10 [–0.20–0]	–0.05 [–0.10–0]	0.08 [0.15–0]
	JW		–0.23 [–0.45–0]	0.42 [0.85–0]	0.11 [0.22–0]		0.09 [0.18–0]
	Muslim			–0.26 [–0.52–0]			
	Universal	–0.47 [–0.94–0]	0.10 [0.20–0]	0.03 [0.06–0]	–0.30 [–0.59–0]	0.02 [0.04–0]	–0.27 [–0.54–0]
	None			0.15 [0.29–0]	–1.16 [–2.33–0]		
Education	None	RC	RC	RC	RC	RC	RC
	Primary	–0.07 [–0.13–0]	0.08 [0.17–0]	0.01 [0.02–0]	0.23 [0.47–0]	–0.10 [–0.20–0]	–0.12 [–0.24–0]
	Secondary+	–0.23 [–0.46–0]	–0.08 [–0.16–0]	–0.18 [–0.37–0]	0.24 [0.48–0]	–0.26 [–0.52–0]	–0.14 [–0.29–0]
Religion: Education	Catholic: None	RC	RC	RC	RC	RC	RC
	Catholic: Primary	RC	RC	RC	RC	RC	RC
	Catholic: Secondary+	RC	RC	RC	RC	RC	RC
	Protestant: None	RC	RC	RC	RC	RC	RC
	Protestant: Primary	–0.08 [–0.15–0]	–0.22 [–0.43–0]	0.07 [0.13–0]	0.08 [0.16–0]	0.06 [0.12–0]	0.14 [0.28–0]
	Protestant: Secondary+	–0.27 [–0.54–0]	–0.13 [–0.27–0]	–0.02 [–0.04–0]	0.13 [0.27–0]	0.01 [0.01–0]	–0.01 [–0.02–0]
	JW: None	RC	RC	RC	RC	RC	RC
	JW: Primary		–0.55 [–1.11–0]	–0.16 [–0.32–0]	–0.15 [–0.30–0]		
	JW: Secondary+		0.70 [1.40–0]				–1.25 [–2.51–0]
	Muslim: None	RC	RC	RC	RC	RC	RC
	Muslim: Primary			0.42 [0.83–0]			
	Muslim: Secondary+			0.06 [0.12–0]			
	Universal: None	RC	RC	RC	RC	RC	RC
	Universal: Primary	–0.05 [–0.09–0]	–0.10 [–0.20–0]	0.10 [0.19–0]	0.30 [0.61–0]	–0.11 [–0.22–0]	
	Universal: Secondary+	–1.03 [–2.06–0]	–0.14 [–0.28–0]	–0.08 [–0.16–0]		–0.72 [–1.44–0]	0.51 [1.02–0]
	None: None	RC	RC	RC	RC	RC	RC
	None: Primary				1.33 [2.65–0]		
	None: Secondary+						
Relationship status	Monogamous	RC	RC	RC	RC	RC	RC
	Single	–0.60 [–1.19–0]	–0.31 [–0.63–0]	–0.30 [–0.60–0]	–0.48 [–0.97–0]	–0.61 [–1.21–0]	–0.21 [–0.41–0]
	Polygamous	0.54 [1.07–0]	0.52 [1.04–0]	0.37 [0.75–0]	0.07 [0.14–0]	0.53 [1.07–0]	0.49 [0.98–0]

Notes: RC – Reference category
JW – Jehovah's Witness

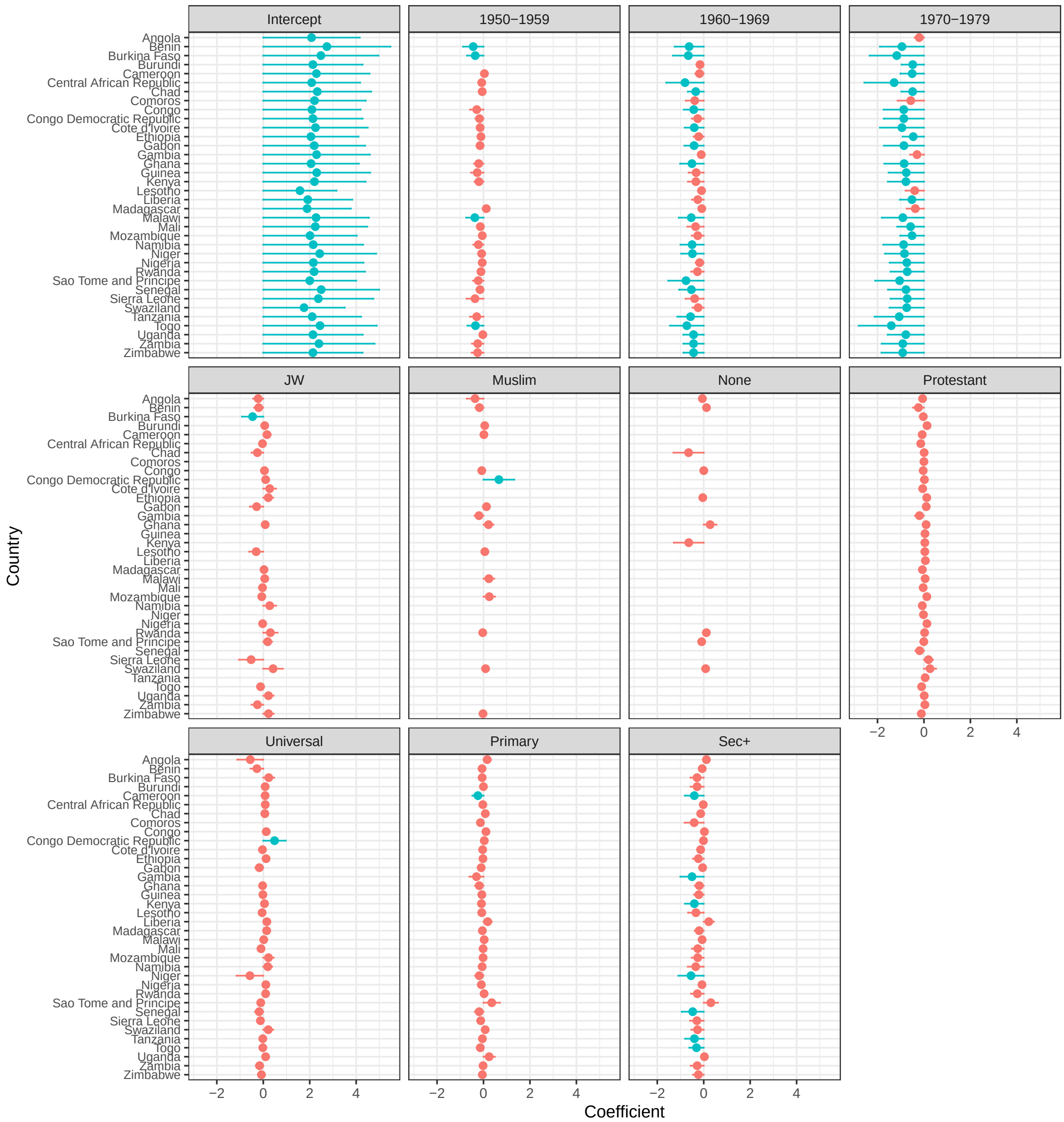
Table 3: (Continued)

Parameter	Variable	Swaziland	Tanzania	Togo	Uganda	Zambia	Zimbabwe
	Intercept	1.33 [2.66–0]	2.11 [4.22–0]	2.05 [4.10–0]	2.18 [4.35–0]	2.13 [4.26–0]	2.23 [4.45–0]
Birth cohort	1940–1949	RC	RC	RC	RC	RC	RC
	1950–1959		–0.27 [–0.53–0]	–0.30 [–0.60–0]	–0.05 [–0.10–0]	–0.05 [–0.09–0]	–0.24 [–0.49–0]
	1960–1969	–0.25 [–0.50–0]	–0.56 [–1.12–0]	–0.74 [–1.48–0]	-0.28 [–0.56–0]	–0.29 [–0.57–0]	–0.47 [–0.95–0]
	1970–1979	–0.72 [–1.44–0]	–1.02 [–2.05–0]	–1.30 [–2.61–0]	–0.63 [–1.26–0]	–0.65 [–1.31–0]	–0.90 [–1.80–0]
Religion	Catholic	RC	RC	RC	RC	RC	RC
	Protestant	0.55 [1.10–0]	0.04 [0.08–0]	0.06 [0.13–0]	–0.13 [–0.26–0]	0.01 [0.02–0]	–0.25 [–0.51–0]
	JW	0.53 [1.06–0]		–0.04 [–0.07–0]	0.25 [0.50–0]	–0.07 [–0.14–0]	–0.04 [–0.09–0]
	Muslim	0.47 [0.95–0]					–0.17 [–0.33–0]
	Universal	0.61 [1.21–0]	–0.05 [–0.10–0]	0.34 [0.68–0]	–0.09 [–0.19–0]	–0.15 [–0.30–0]	–0.28 [–0.55–0]
	None	0.50 [1–0]					
Education	None	RC	RC	RC	RC	RC	RC
	Primary	0.65 [1.31–0]	–0.18 [–0.36–0]	0.03 [0.07–0]	–0.03 [–0.05–0]	0.05 [0.11–0]	–0.18 [–0.35–0]
	Secondary+	0.45 [0.91–0]	–0.06 [–0.13–0]	–0.28 [–0.56–0]	–0.03 [–0.06–0]	0 [–0.01–0]	–0.34 [–0.68–0]
Religion: Education	Catholic: None	RC	RC	RC	RC	RC	RC
	Catholic: Primary	RC	RC	RC	RC	RC	RC
	Catholic: Secondary+	RC	RC	RC	RC	RC	RC
	Protestant: None	RC	RC	RC	RC	RC	RC
	Protestant: Primary	–0.62 [–1.25–0]	0.09 [0.17–0]	–0.11 [–0.23–0]	0.13 [0.25–0]	0.06 [0.12–0]	0.16 [0.32–0]
	Protestant: Secondary+	–0.48 [–0.95–0]	–0.38 [–0.76–0]	–0.03 [–0.07–0]	0.01 [0.02–0]	0.03 [0.05–0]	0.22 [0.44–0]
	JW: None	RC	RC	RC	RC	RC	RC
	JW: Primary	–0.29 [–0.58–0]		0.04 [0.08–0]	–0.05 [–0.10–0]	–0.24 [–0.49–0]	0.25 [0.50–0]
	JW: Secondary+	–0.64 [–1.29–0]		0.09 [0.18–0]		–0.56 [–1.11–0]	0.28 [0.57–0]
	Muslim: None	RC	RC	RC	RC	RC	RC
	Muslim: Primary	–0.83 [–1.66–0]					0.24 [0.47–0]
	Muslim: Secondary+	–0.56 [–1.12–0]					0.03 [0.06–0]
	Universal: None	RC	RC	RC	RC	RC	RC
	Universal: Primary	–0.55 [–1.09–0]	0.22 [0.45–0]	–0.31 [–0.62–0]	0.27 [0.54–0]	0.18 [0.37–0]	0.25 [0.49–0]
	Universal: Secondary+	–0.64 [–1.27–0]	–0.14 [–0.29–0]	–0.09 [–0.18–0]	–0.40 [–0.80–0]	0.18 [0.36–0]	
	None: None	RC	RC	RC	RC	RC	RC
	None: Primary	–0.64 [–1.28–0]					
	None: Secondary+	–0.60 [–1.20–0]					
Relationship status	Monogamous	RC	RC	RC	RC	RC	RC
	Single	–0.21 [–0.42–0]	–0.22 [–0.45–0]	–0.34 [–0.69–0]	–0.45 [–0.90–0]	–0.42 [–0.84–0]	–0.30 [–0.60–0]
	Polygamous	0.59 [1.19–0]	0.44 [0.88–0]	0.65 [1.31–0]	0.46 [0.93–0]	0.43 [0.86–0]	0.49 [0.98–0]

Notes: RC – Reference category
JW – Jehovah's Witness

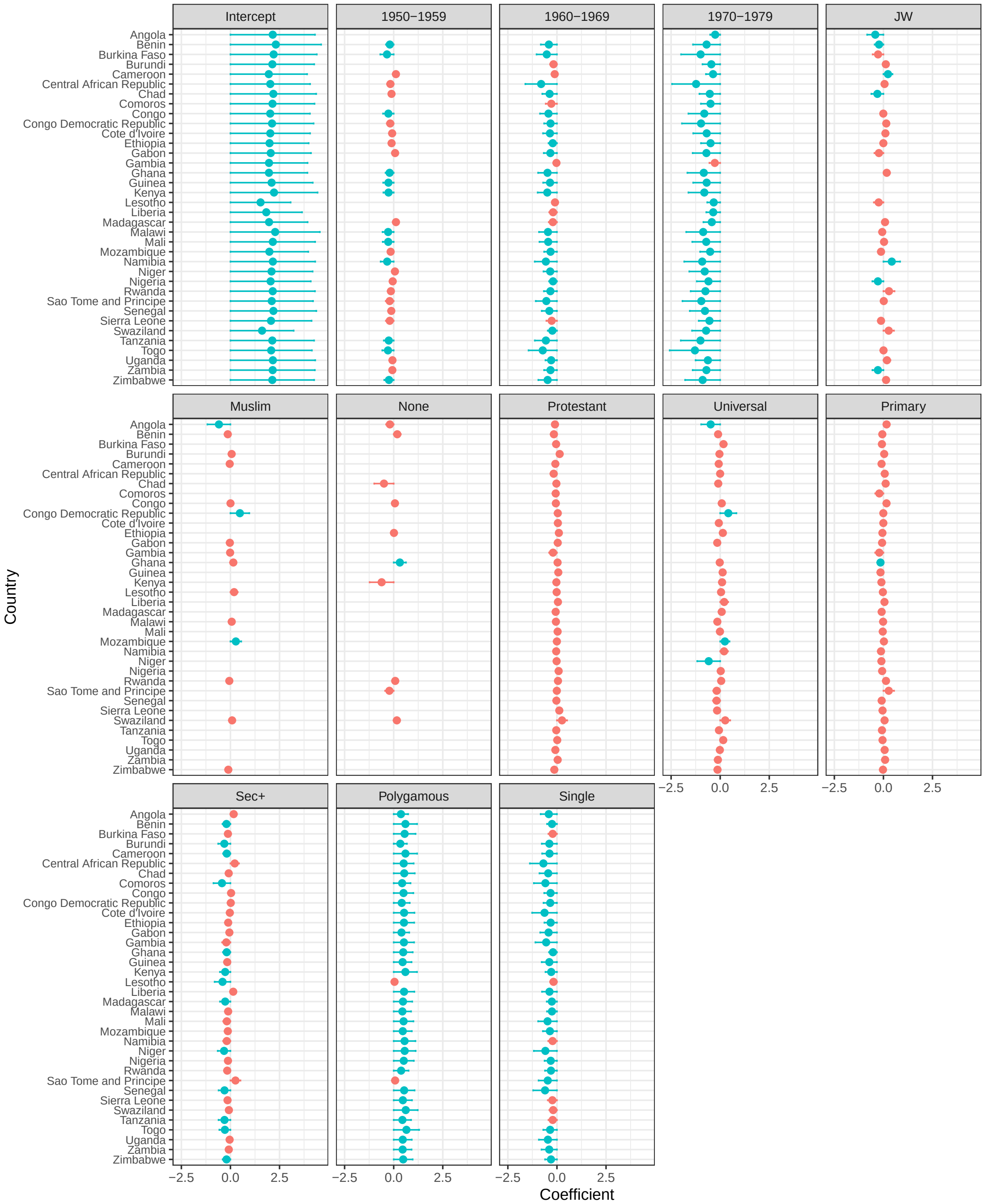
Figure 3 shows the coefficients and 95% confidence intervals of the alternative models (without interaction, without relationship status, and without relationship status or interaction) with their associated p-values in colour, blue for p-value <0.05 and red for other. In Figure 3, "JW" is the religion Jehovah's Witness and "Sec+" is the education level "secondary or more."

Figure 3: Coefficients of additional Poisson models



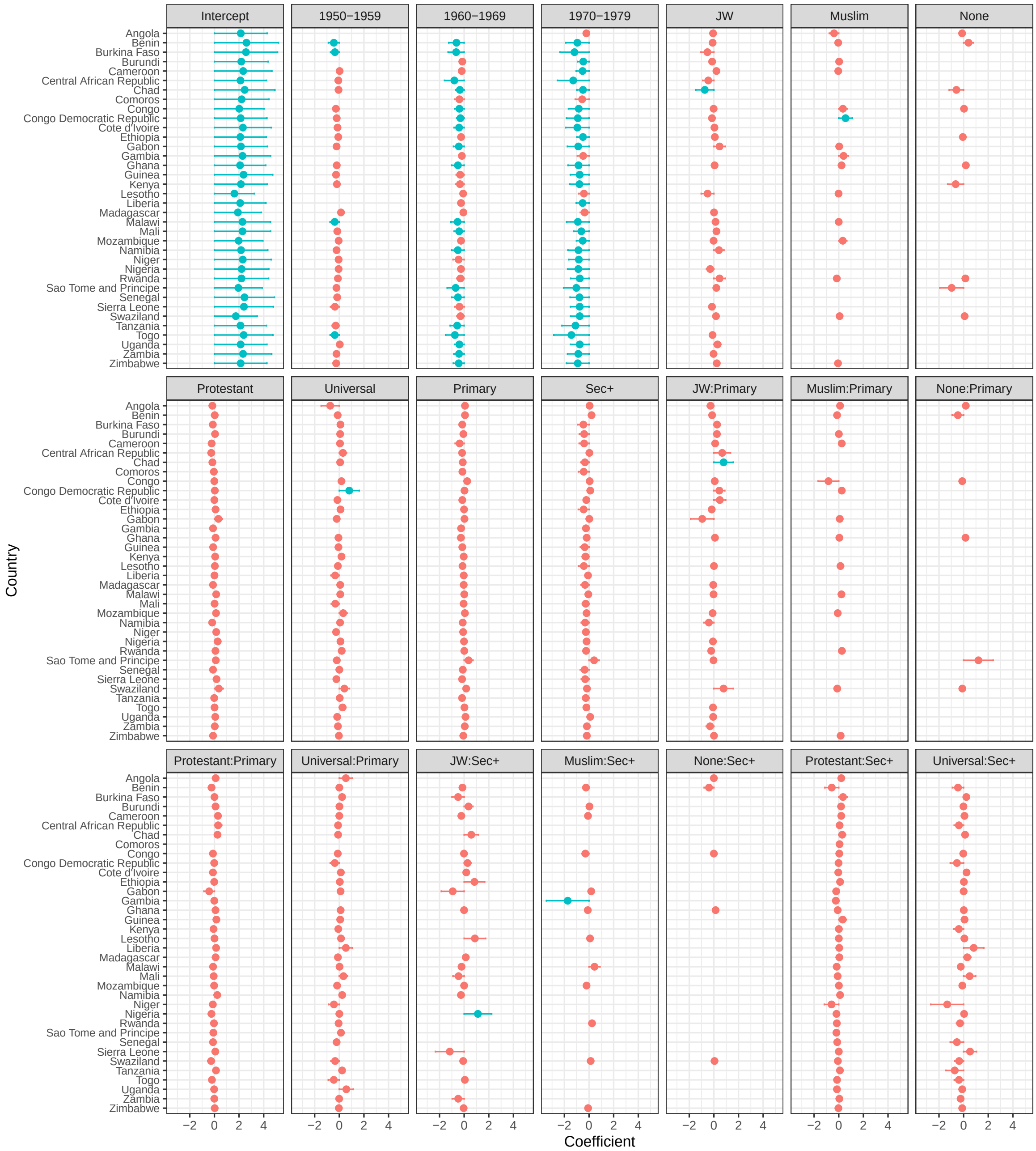
Note: Poisson regression: Coefficients by country and variable, without interaction or marital status.

Figure 3: (Continued)



Note: Poisson regression: Coefficients by country and variable, without interaction term.

Figure 3: (Continued)



Note: Poisson regression: Coefficients by country and variable, with interaction but without marital status.

There are no differences in the mean number of children between Catholic and Protestant men across countries; however, men in the youngest cohorts (1970–1979) have, on average, fewer children than men born between 1940 and 1949 across countries. Polygamy consistently has a strong positive effect on fertility across all countries, while the effect of education is weaker and varies across contexts. In most countries, men with primary or secondary education do not have significantly fewer children than those with no education. In some countries like Lesotho and Zimbabwe, secondary or more education marginally reduces fertility, but in others, such as Angola and Benin, no significant difference compared to men with no education is observed. The interaction between education and religion largely does not yield substantial variations in fertility outcomes. While some country-specific effects exist, overall, the role of religion does not significantly alter the relationship between education and fertility. Similarly, the effects of education and religion individually are reduced for almost all countries. These findings suggest that other contextual factors, such as economic conditions, social norms, and policy environments, may play a larger role in shaping male fertility trends. The Poisson regression results indicate that relationship status plays a more significant role in male fertility than education or religion. This association is further observed in the other models, where education still has a relatively weak association with children ever born.

5. Discussion and conclusion

This study examined the mean number of children men have by education, religious affiliation, relationship status, and birth cohort across 36 sub-Saharan African countries. Across all countries, men in polygamous unions have significantly more children than their monogamous or single counterparts, aligning with previous findings (Schoumaker 2017). Conversely, single men are generally likely to have fewer children than men in monogamous relationships. Furthermore, men born in later cohorts, specifically 1970–1979, report a lower mean number of children than those in earlier cohorts, likely reflecting the impacts of accelerated modernisation and urbanisation over time. As Menashe-Oren and Sánchez-Páez (2023) point out, men in urban areas typically have fewer children than their rural counterparts, suggesting that processes associated with modernisation, such as increased access to family planning and shifting social norms, may be driving this trend. The study finds a weak association between education and male fertility, likely reflecting counteracting forces: While education delays marriage and childbearing, higher-educated men may have greater access to resources that facilitate larger families and may delay marriage but maintain relatively high fertility within unions. Higher education is associated with social and economic advantages, such as increased income (Nnyanzi and Kilimani 2018) and better marriage prospects for men (Pesando 2021), which may counteract fertility-reducing effects. Thus, highly educated men may be better positioned to support larger families, maintaining relatively high fertility despite delayed marriage. Additionally, the persistence of polygamy and traditional family structures may weaken the direct effect of education on fertility outcomes. Lastly, male fertility is less biologically constrained by age than female fertility, reducing the direct impact of schooling years on childbearing.

Furthermore, religion, as with education, had an inconsistent relationship with the mean number of children, although variations exist on a country-specific level. For instance, while Muslims had more children in Congo DR than Catholics, in Angola, Muslim men have fewer children. In addition, results suggest that education's impact on fertility is inconsistent across religious groups. The interaction effects in most countries are not strong, suggesting that education's effect on male fertility is largely independent of religious affiliation. Future research should examine how specific religious doctrines influence male fertility decisions, particularly regarding contraception, ideal family size, and polygamous unions. Longitudinal studies could also help determine whether changing socioeconomic conditions alter these relationships over time. Additionally, in some religious groups, men with secondary or more education constitute a small proportion of the sample. As a result, statistical power is limited in detecting differences in fertility patterns for these subgroups. This limitation should be kept in mind when interpreting results.

Despite the strengths of this study, several limitations should be acknowledged. A key limitation of this study is the reliability of male fertility data, as recall bias and under-reporting are common in surveys (Rendall et al. 2006; Zhang 2008). Men tend to under-report fertility due to social desirability bias and recall errors, which may affect our estimates. Under-reporting of children by men, especially in polygamous settings, may mean that actual male fertility is higher than reported. This should be considered when interpreting results. Additionally, we did not control for partners' education or residence (rural/urban), which may influence fertility outcomes. Considering the interaction between religion and relationship status could also provide a more nuanced understanding of male fertility in sub-Saharan Africa. Some religious groups themselves, such as Jehovah's Witnesses and Universal believers, and the subgroup of highly educated men in some religious groups have small sample sizes, which may contribute to unstable estimates and reduce statistical power. As a result, findings for these groups should be interpreted with caution, and future research should consider larger pooled samples. Future research should explore these dynamics using alternative datasets with more robust male fertility reporting.

While the findings of the main model suggest that the association between education and the number of children ever born is relatively weak, it may be partially explained by the inclusion of relationship status in the main model. In models without relationship status, a weak association is still observed, albeit a stronger association than in the main model. This suggests that part of education's influence on male fertility may operate through union patterns. As noted in prior literature, education may reduce the likelihood of entering polygamous unions, which are consistently associated with higher fertility. In this context, relationship status could act as a mediator of the effect of education.

By controlling for relationship status, the main model likely estimates the direct effect of education on fertility rather than its total effect. Moreover, the model without the interaction showed a stronger relationship in many more countries, although still a weak association overall. This observation is evident in only some countries and mostly for men with secondary and higher education levels.

Overall, the study suggests that, within many sub-Saharan African countries, factors such as relationship status and birth cohort play a more decisive role in male fertility than education and religion. This finding underscores the importance of focusing on country-specific relationship dynamics and the influence of modernisation across birth cohorts when considering high-fertility settings. Furthermore, policy interventions should consider relationship norms and the cultural context of male fertility in sub-Saharan Africa. Male fertility data in DHS surveys, as with other surveys, is subject to recall bias and under-reporting, particularly among older respondents (Schoumaker 2017; Rendall et al. 2006). This limitation should be considered when interpreting findings. These findings highlight the need to engage men more actively in fertility-related policies. The fact that male education does not strongly reduce fertility suggests that economic stability and social expectations may outweigh educational influences. Policies aimed at reducing high fertility should not only focus on female education and contraception access but also address male reproductive decision-making and how men's reproductive choices are influenced by economic stability, marriage timing, and religious values. Given the significant fertility differences between monogamous and polygamous men, interventions targeting family planning among polygamous households could be particularly effective. Additionally, future policies should consider how religious institutions shape male fertility norms, integrating faith-based approaches to promote balanced fertility behaviours. Future research should explore how changes in employment and urbanisation affect male fertility intentions over time.

References

Adhikari, S., Lutz, W., and Kebede, E. (2024). Forecasting Africa's fertility decline by female education groups. *Proceedings of the National Academy of Sciences* 121(46): e2320247121. doi:10.1073/pnas.2320247121.

Asongu, S.A., Nounamo, Y., Njangang, H., and Tadadjeu, S. (2021). Gender inclusive intermediary education, financial stability and female employment in the industry in sub-Saharan Africa. *Finance Research Letters* 43(C): 101968. doi:10.1016/j.frl.2021.101968.

Bankole, A. and Audam, S. (2011). Fertility preferences and contraceptive use among couples in sub-Saharan Africa. *African Population Studies* 25(2). doi:10.11564/25-2-246.

Bankole, A., Biddlecom, A., Singh, S., Guiella, G., and Zulu, E. (2007). Sexual behavior, knowledge and information sources of very young adolescents in four sub-Saharan African countries. *African Journal of Reproductive Health* 11(3): 28–43.

Berger, H. and Dasré, A. (2024). Religious affiliation, education, and fertility in sub-Saharan Africa. *World Development* 184: 106723. doi:10.1016/j.worlddev.2024.106723.

Bietsch, K.E. (2015). Men's attitudes towards contraception in sub-Saharan Africa. *African Journal of Reproductive Health* 19(3): 41–54.

Blackstone, S.R., Nwaozuru, U., and Iwelunmor, J. (2017). Factors influencing contraceptive use in sub-Saharan Africa: A systematic review. *International Quarterly of Community Health Education* 37(2): 79–91. doi:10.1177/0272684X16685254.

Bongaarts, J. (2010). The causes of educational differences in fertility in sub-Saharan Africa. *Vienna Yearbook of Population Research* 8: 31–50. doi:10.1553/populationyearbook2010s31.

Bratsberg, B., Kotsadam, A., and Walther, S. (2021). Male fertility: Facts, distribution and drivers of inequality. Bonn: IZA. (IZA Discussion Paper Series 14506): 1–53.

Butame, S. (2019). The prevalence of modern contraceptive use and its associated socio-economic factors in Ghana: Evidence from a demographic and health survey of Ghanaian men. *Public Health* 168: 128–136. doi:10.1016/j.puhe.2018.12.020.

Cameron, A.C. and Trivedi, P.K. (2013). *Regression analysis of count data. Second edition*. Cambridge: Cambridge University Press. doi:10.1017/CBO9781139013567.

Chae, S. and Agadjanian, V. (2022). The transformation of polygyny in sub-Saharan Africa. *Population and Development Review* 48(4): 1125–1162. doi:10.1111/padr.12524.

Choi, K.H. and Hamilton, E.R. (2016). Understanding patterns of contraceptive use among never married Mexican American women. *Demographic Research* 34(40): 1129–1160. doi:10.4054/DemRes.2016.34.40.

Church, A.C., Ibitoye, M., Chettri, S., and Casterline, J.B. (2023). Traditional supports and contemporary disrupters of high fertility desires in sub-Saharan Africa: A scoping review. *Reproductive Health* 20(86). doi:10.1186/s12978-023-01627-7.

Demeke, H., Legese, N., and Nigussie, S. (2024). Modern contraceptive utilization and its associated factors in East Africa: Findings from multi-country demographic and health surveys. *PLoS One* 19(1): e0297018. doi:10.1371/journal.pone.0297018.

DHS program (2023). The DHS program – Data processing. Rockville: The Demographic and Health Surveys (DHS) Program. https://dhsprogram.com/data/Data-Processing.cfm.

Doepke, M. and Tertilt, M. (2018). Women's empowerment, the gender gap in desired fertility, and fertility outcomes in developing countries. *AEA Papers and Proceedings* 108: 358–362. doi:10.1257/pandp.20181085.

Dudel, C. and Klüsener, S. (2021). Male–female fertility differentials across 17 high-income countries: Insights from a new data resource. *European Journal of Population* 37(2): 417–441. doi:10.1007/s10680-020-09575-9.

Fenske, J. (2015). African polygamy: Past and present. *Journal of Development Economics* 117: 58–73. doi:10.1016/j.jdeveco.2015.06.005.

Garenne, M. (2022). Marriage in sub-Saharan Africa. In: O. Odimegwu, C. and Adewoyin, Y. (eds.). *The Routledge Handbook of African Demography*. London: Routledge: 151–180.

Goujon, A., Lutz, W., and KC, S. (2015). Education stalls and subsequent stalls in African fertility: A descriptive overview. *Demographic Research* 33(47): 1281–1296. doi:10.4054/DemRes.2015.33.47.

Grant, M.J. (2015). The demographic promise of expanded female education: Trends in the age at first birth in Malawi. *Population and Development Review* 41(3): 409–438. doi:10.1111/j.1728-4457.2015.00066.x.

Hill, N.J., Siwatu, M., and Robinson, A.K. (2014). "My religion picked my birth control": The influence of religion on contraceptive use. *Journal of Religion and Health* 53: 825–833. doi:10.1007/s10943-013-9678-1.

Kan, M. (2024). Religion and contraceptive use in Kazakhstan. *Demographic Research* 50(21): 547–582. doi:10.4054/DemRes.2024.50.21.

Kim, J. (2023). Female education and its impact on fertility. *IZA World of Labor* (228). doi:10.15185/izawol.228.v2.

Lumley, T. (2020). Survey: Analysis of complex survey samples. R package version 4.0.

Lutz, W., Goujon, A., KC, S., Stonawski, M., and Stilianakis, N. (eds.) (2018). *Demographic and human capital scenarios for the 21st century: 2018 assessment for 201 countries*. Luxembourg: Publications Office of the European Union. doi:10.2760/835878.

McQuillan, K. (2004). When does religion influence fertility? *Population and Development Review* 30(1): 25–56. doi:10.1111/j.1728-4457.2004.00002.x.

Menashe-Oren, A. and Sánchez-Páez, D.A. (2023). Male fertility and internal migration in rural and urban sub-Saharan Africa. *European Journal of Population* 39(10): 1–40. doi:10.1007/s10680-023-09659-2.

Nkonde, H., Mukanga, B., and Daka, V. (2023). Male partner influence on women's choices and utilisation of family planning services in Mufulira district, Zambia. *Heliyon* 9(3): e14405. doi:10.1016/j.heliyon.2023.e14405.

Nnyanzi, J.B. and Kilimani, N. (2018). Estimation of disaggregated impacts of education expansion on economic growth in sub-Saharan Africa. *Modern Economy* 9(12): 2119–2149. doi:10.4236/me.2018.912132.

Pesando, L.M. (2021). Educational assortative mating in sub-Saharan Africa: Compositional changes and implications for household wealth inequality. *Demography* 58(2): 571–602. doi:10.1215/00703370-9000609.

Rendall, M.S., Admiraal, R., Handcock, M.S., and Joyner, K. (2006). *Early entry to fatherhood estimated from men's and women's survey reports in combination*. Paper presented at The National Survey of Family Growth Research Conference, October 19–20, 2006.

Schoumaker, B. (2017). Measuring male fertility rates in developing countries with Demographic and Health Surveys: An assessment of three methods. *Demographic Research* 36(28): 803–850. doi:10.4054/DemRes.2017.36.28.

Schoumaker, B. (2019). Male fertility around the world and over time: How different is it from female fertility? *Population and Development Review* 45(3): 459–487. doi:10.1111/padr.12273.

Speizer, I.S. and Calhoun, L.M. (2022). Her, his, and their fertility desires and contraceptive behaviours: A focus on young couples in six countries. *Global Public Health* 17(7): 1282–1298. doi:10.1080/17441692.2021.1922732.

Stonawski, M., Skirbekk, V., Hackett, C., Potančoková, M., Connor, P., and Grim, B. (2015). Global population projections by religion: 2010–2050. In: Grim, B., Johnson, T., Skirbekk, V., and Zurlo, G. (eds.). *Yearbook of International Religious Demography 2015*. Leiden: Brill: 99–116. doi:10.1163/9789004297395_004.

Turner, N. and Götmark, F. (2023). Human fertility and religions in sub-Saharan Africa: A comprehensive review of publications and data, 2010–2020. *African Journal of Reproductive Health* 27(1): 119–171.

Zhang, L. (2008). Religious affiliation, religiosity, and male and female fertility. *Demographic Research* 18(8): 233–262. doi:10.4054/DemRes.2008.18.8.

3. Conclusion

The four studies in this dissertation challenge the conventional assumption that education is uniformly linked to delayed childbearing and lower fertility levels. Instead, they reveal a more complex relationship: the demographic patterns associated with education vary depending on how it relates to literacy, relational autonomy, and socio-cultural capital. The Bayesian reconstruction shows that education-specific fertility declines have been uneven across regions. The literacy-focused study emphasises that the ability to read, and presumably comprehend, not just years of schooling, is associated with variations in age at first birth in high-fertility settings. The paper on spousal age gap in this thesis demonstrates how partner dynamics are associated with the relationship between education and spousal age gaps, while the study focusing on male fertility reveals that relationship status appears to shape the association between education and male fertility patterns. Across these domains, education emerges not as a deterministic input but as a multidimensional process embedded in contextually shaped life courses.

Each paper highlights a specific pathway of the conceptual framework in Figure 1.1. The following sub-sections expand on the key findings of each of the papers and their overall contributions. This dissertation advances understanding of the multifaceted relationship between education and fertility in low- and middle-income countries, with particular attention to sub-Saharan Africa. Taken together, the papers provide new insights and extend the literature on demographic transitions and the associations between education and fertility behaviours.

3.1. Key Findings

Paper 1: Reconstructing education-specific fertility rates

This paper provides empirical evidence on demographic transitions and contributes to demographic methods, estimation techniques, and the understanding of how education relates to fertility. The study combines a generalised linear model and a Bayesian hierarchical model to integrate data from multiple sources. The results are cross-country comparative education and age-specific fertility rates. This approach enables a comprehensive reconstruction of education-specific fertility rates, which helps understand demographic trends in low- and middle-income countries. By combining data from the DHS, UN WPP, and Wittgenstein Centre, the study overcomes limitations associated with the individual data sources, providing more reliable and consistent estimates. This progress is particularly vital for regions where data quality has historically been an issue due to misreporting of ages, omissions, and data heaping within the DHS (Al Zalak & Goujon, 2017; Schoumaker, 2011). The results consistently show that women with higher education levels exhibit the lowest fertility rates across all countries and periods. This finding elaborates further on the significant relationship between education and lower fertility rates and emphasises the importance of educational attainment in demographic projections and policy-making.

In the study, countries that experienced the demographic transition, for instance, many Latin American countries, had lower age-specific fertility rates than sub-Saharan African countries experiencing stalls in the fertility transition. These declines are particularly pronounced among women with higher education levels, suggesting that higher levels of education are associated with observed lower fertility patterns. The study also highlights the narrowing of educational differences in fertility rates in countries that have experienced demographic transitions. In contrast, countries still undergoing or that have yet to undergo such transitions show more pronounced educational disparities in fertility rates.

The provided reconstructed education-specific fertility rates offer valuable inputs for future population projections. These rates pave the way for more accurate forecasting and projections of demographic trends, and potentially inform policy decisions related to education, family planning, and socio-economic development. Additionally, the study provides empirical evidence of fertility transitions on a larger scale, particularly for low- and middle-income countries. This evidence offers valuable inputs for discussions on educational policies in relation to demographic change.

Paper 2: Education, literacy and fertility

The study examines the role of literacy skills in the relationship between education and fertility, particularly in sub-Saharan Africa, where literacy rates are often low and educational attainment varies.

The study finds that among women with no education or with only primary education, those who are illiterate tend to have higher fertility rates than their literate counterparts at the same educational level. This finding suggests that literacy skills are strongly associated with lower fertility rates, even among women with limited formal education. Literacy skills, overall, do not show a significant association with the timing of first births. While literacy is clearly linked to overall fertility levels, other factors, including length of schooling, may be more relevant in determining the age at which women have their first child. Furthermore, the findings highlight a strong relationship between higher levels of education (secondary and above) and delayed first births and lower fertility rates. These findings indicate a consistent association between higher education and fertility outcomes in sub-Saharan Africa. The study highlights the importance of incorporating literacy skills into demographic research, particularly in regions where educational attainment may not translate to literacy skills. This finding underscores the need for more comprehensive education measures in fertility studies.

These results suggest that improving literacy skills, even among women with limited formal education, can be associated with differences in fertility outcomes. This finding has important implications for policy-makers seeking educational initiatives beyond formal schooling.

Paper 3: Shifting spousal age gaps in Ghana and Kenya

The third paper examines how education is associated with differences in the mean spousal age gap in Ghana and Kenya, particularly among couples with a high age gap of ten years and above. This study highlights how educational attainment is linked to variation in the proportion of couples with high age gaps and to shifts in spousal age differences across survey years 1990–1994 and 2020–2024.

The study finds that higher levels of education in Ghana and Kenya are associated with lower proportions of couples with a high age gap and a lower mean spousal age gap. This observation persists when focusing on male and female education only, as well as the dyadic education level of the couple. Men and women with secondary or higher education levels tend to experience lower mean spousal age gaps than those with lower levels of education at each survey year in Ghana and Kenya, which aligns with findings from other regions. The results indicate that the mean spousal age gap has decreased across survey years in both Ghana and Kenya. However, overall, the percentage change is higher in Ghana than in Kenya. In Kenya, behavioural effects within both men's and women's education groups were most closely associated with most of the decline in large spousal age gaps, reflecting a growing share of unions with smaller age differences. In Ghana, by contrast, structural effects linked to rising male education levels were more pronounced than female education, with men's education contributing more strongly to the decline in spousal age gaps. Nonetheless, in all estimates and countries, the composition effect—reflecting the distribution of couples with high age gaps across education groups—was associated with reductions in the spousal age gap between the completed latest and oldest five-year survey periods. The study highlights differences between Kenya and Ghana within sub-Saharan Africa. The decline in mean spousal age gaps is smaller in Kenya (East Africa) than in Ghana (West Africa). Furthermore, the compositional effect of education moved in opposite directions across the two countries: in Kenya, where the education-age gap gradient was relatively flat, shifts in the education distribution were associated with a slight upward push in the mean spousal age gap. In Ghana, by contrast, rising male education levels aligned more clearly with smaller spousal age gaps, so the compositional effect contributed to a reduction. The opposing directions indicate that the relationship between educational attainment and spousal age gaps varies by gender and differs between Ghana and Kenya, as shown in the 2020–2024 survey years.

This paper contributes to the limited research on male fertility behaviour and education in sub-Saharan Africa. By examining the spousal age gap with a focus on men's, women's, and couples' dyadic education levels, the study provides new insights into the relationship between education and men's fertility behaviours. The findings underscore the relevance of educational composition for understanding fertility trends. The study provides empirical evidence on how changes in educational attainment are associated with the proportion of couples with a high age gap and the mean spousal age gap over time. The results suggest that policies aimed at increasing educational attainment, particularly for women, may help support narrower age gaps in unions. This finding has important implications for demographic planning and gender equality initiatives in the region.

Paper 4: Education, religion, and male fertility

The final paper examines the relationship between education, religious affiliation, partnership status and male fertility levels across countries in sub-Saharan Africa. This study focuses on whether educational attainment has a similar negative relationship with male completed family size as with women in sub-Saharan Africa.

The study finds that the relationship between education and men's completed family size is not uniform across sub-Saharan Africa: in many cases, the association is weak, but relatively clearer at the secondary level and above in a few countries. In most countries, the birth cohort of the man and his relationship status were more strongly associated with his fertility level than his education or religious affiliation. Fertility levels were significantly lower among men born in the 1970 to 1979 birth cohort than among other (1940-1969) men, and polygamous men were observed to have more children than other men, as established in previous studies (Menashe-Oren & Sánchez-Páez, 2023; Schoumaker, 2017).

While the main results hold for many countries, there were still country-specific variations in this relationship. In those countries where education was associated with men's completed family size, the clearest differences were observed at the secondary and higher levels, with these men having fewer children than those with lower education levels. Furthermore, the results support a more targeted approach to fertility studies in the region. Focusing on male fertility broadens the understanding of the fertility trajectory in sub-Saharan Africa.

Overarching Insights

Across the first three studies, a consistent theme is the negative association between female education and fertility, though this relationship is not uniform. The association is strongest at the secondary level and above, while literacy further differentiates behaviours among women with little or no schooling. Women with higher levels of education tend to have fewer children and later ages at first birth, but the strength of these associations varies across countries and over time. Analyses of spousal age gaps in Ghana and Kenya show that education is linked to smaller age gaps, though the relative contributions of compositional and behavioural factors differ by country. For men, however, the final paper finds that education is more weakly related to completed family size, with relationship status—particularly polygamy—and birth cohort having stronger associations.

Together, these studies suggest that education connects to fertility through multiple, interlinked dimensions: structural (years of schooling and educational attainment), cognitive (literacy), and behavioural (age at union). The findings also underscore that these associations are gendered and context-dependent, highlighting the need for disaggregated analyses that consider women and men separately. Conventional models risk overlooking these dimensions—for instance, the role of literacy in differentiating fertility at low levels of schooling, or the weaker associations observed between education and men's completed family size. Recognising this complexity can help refine demographic research and policy debates, ensuring that education and literacy are considered in relation to gender, relationship status, and diverse national contexts.

3.2. Concluding Remarks

This dissertation emphasises the strong associations between female education and fertility patterns in low- and middle-income countries, particularly in sub-Saharan Africa. While these findings are not causal, they strongly suggest that education—especially at the secondary level and above—plays a central role in shaping demographic patterns and deserves close attention in both research and policy debates. It further highlights the weak relationship between education and male fertility, emphasising that the education-fertility relationship differs by gender. The research presented in these papers not only advances understanding of fertility change and demographic patterns in these regions but also contributes valuable methodological innovations and empirical evidence that will serve as a foundation for future studies in demography.

Broader impact and contributions

This dissertation makes several key contributions to the field:

1. Novel data sets and methodologies: By integrating data from the Demographic and Health Surveys, United Nations World Population Prospects, and the Wittgenstein Centre for Demography and Global Human Capital, this research introduces new, robust data sets and innovative methodologies for reconstructing education-specific fertility rates. These tools will be invaluable for demographers seeking to understand historical and future fertility trends in diverse contexts.

2. Nuanced insights into fertility transitions: This dissertation moves beyond the well-established association between female education and fertility by showing how the relationship varies across educational level, duration of schooling, contexts, and gender. The analyses demonstrate that the negative education-fertility gradient is strongest from secondary education upward, while literacy skills and school duration differentiate fertility behaviours among women with little or no formal education. These insights can inform family planning and educational policy discussions in sub-Saharan Africa and other low- and middle-income settings.

3. Gender and educational disparities: The research underscores disparities in educational attainment and literacy skills across different regions and their strong associations with fertility outcomes. By shedding light on these disparities, the dissertation points to the importance of educational initiatives that address the specific needs of women in sub-Saharan Africa and other similar regions. Furthermore, it advances the understanding of male fertility and educational attainment, showing that in sub-Saharan Africa, education is negatively associated with female fertility patterns, but the association is weaker and less consistent in men, with clearer differences only at secondary and higher levels in a few countries.

4. Policy implications: The findings underscore the importance of comprehensive educational policies outside enrolment to focus on quality education and skill acquisition. Such policies can support gender equality, foster socio-economic development, and, in the long term, be relevant to broader discussions of demographic change. These findings may inform future research directions and discussions on education-related interventions, particularly regarding how literacy and male involvement are associated with fertility outcomes in sub-Saharan Africa.

This dissertation, with its contributions, is not without limitations. The primary data source, the Demographic and Health Surveys (DHS), has limitations such as measurement errors (e.g., age heaping), literacy misclassification, and retrospective birth reporting, which may introduce biases (Schoumaker, 2011, 2014). This thesis attempts to maintain contextual sensitivity by examining country-specific gender norms, structures, and education quality. Nevertheless, the interpretation of findings falls within frameworks available and the inherent limitations of demographic quantification. Future research could enrich these findings through qualitative or mixed-methods designs that bring voices and lived experiences into dialogue with statistical patterns. While this dissertation provides significant contributions, it also opens up new avenues for future research. There is a need for further studies that explore the complex interactions between education, literacy, and fertility in different cultural and socio-economic contexts. Future research should also investigate the long-term implications of educational policies for demographic trends and consider how emerging factors, such as technological advancements and economic development, may relate to education and fertility in sub-Saharan Africa.

Concluding thoughts

The core theoretical insight of this dissertation is that educational attainment alone cannot fully account for fertility decline in high-fertility settings. Instead, it depends on how education is associated with changes in agency, particularly literacy acquisition, delayed unions, and shifts in gendered relational norms. These transformations are contingent, mediated, and uneven across populations. As such, researchers should conceptualise fertility transitions in sub-Saharan Africa as structurally embedded and relationally negotiated processes, rather than linear outcomes of schooling. Demographic theory must move beyond education as a scalar input to a more nuanced account of education as a dynamic social experience.

In conclusion, this dissertation underscores the significant associations between education and demographic outcomes. It provides a deeper understanding of the relationship between education and fertility, laying the groundwork for future research and policy-making for low- and middle-income countries. The journey undertaken in this research highlights both the challenges and the opportunities in situating education within broader processes of demographic change and progress. The findings of this dissertation resonate beyond the academic community, offering actionable demographic insights applicable to health, education, and gender equity policy. This dissertation is a valuable resource for researchers, policy-makers, and practitioners committed to advancing the knowledge of fertility and education in the context of global development. As the famous Ghanaian pioneer of co-education and female education, Dr James Emman Kwegyir Aggrey, once said, "... if you educate a man, you educate an individual, but if you educate a woman, you educate a whole nation". The saying underscores the value of female education in nation-building, particularly in Africa.

References

Al Zalak, Z., & Goujon, A. (2017). *Assessment of the data quality in demographic and health surveys in Egypt* (tech. rep.). Vienna Institute of Demography Working Papers.

Menashe-Oren, A., & Sánchez-Páez, D. A. (2023). Male fertility and internal migration in rural and urban sub-Saharan Africa. *European Journal of Population*, *39*(1), 10.

Schoumaker, B. (2011). Omissions of births in dhs birth histories in sub-Saharan Africa: Measurement and determinants. *Population Association of America*.

Schoumaker, B. (2014). *Quality and consistency of dhs fertility estimates, 1990 to 2012*. ICF International Rockville, Maryland.

Schoumaker, B. (2017). Measuring male fertility rates in developing countries with demographic and health surveys: An assessment of three methods. *Demographic Research*, *36*, 803–850.