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The Underlying Role of Education, Gender Inequality and Health in Economic Development:

Sub-Saharan Africa, 1920 – 2013

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List of Abbreviations

2 SLS	Two-Stage Least Squares
ACTD	African Commodity Trade Database
AFB	Afrobarometer data
ALE	Active Life Expectancy
ANC	Antenatal Clinic
ASF	Animal Source Food
DHS	Demographic Health Survey
DMSP	Defense Meteorological Satellite Program
DN	Digital Number
FAO	Food and Agriculture Organization
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
GIS	Geographic Information System
GS2SLS	Generalized Spatial Two-Stage Least Squares
GTS	Global Technical Strategy for Malaria
HYDE	History Database of Global Environment
IPTp	Intermittent Preventive Treatment in Pregnancy
IPUMS-I	Integrated Public Use Microdata Series; International
IR	Individual Recode
ITN	Insecticide-Treated Bednets
KAP	Knowledge, Attitudes, and Practices
KEMRI	Kenyan Medical Research Institute
LSDV	Least Square Dummy Variable
MEI	Malaria Ecology Index
MENA	Middle East and North Africa
MEPV	Major Episode of Political Violence
MERG	Monitoring and Evaluation Working Group
MIM	Multilateral Initiative on Malaria
MIS	Malaria Indicator Survey
NOAA	National Oceanic and Atmospheric Administration
OECD	Organization for Economic Co-operation and Development
OLG	Overlapping Generations Model
OLS	Ordinary Least Squares
OLS	Operational Linescan System
PCA	Principal Component Analysis
PMS	Patent Medicine Sellers
PPP	Purchasing Power Parity
RBM	Roll Back Malaria
RCS	Repeated Cross-Sectional
SAR	Spatial AutoRegressive
SPI	Standardized Precipitation Index
SSA	Sub-Saharan Africa
SWAC	Sahel and West African Club
TSI	Tsetse Suitability Index
WHO	World Health Organization

List of Country Abbreviations

ao	Angola
bf	Burkina Faso
bi	Burundi
bj	Benin
bw	Botswana
cd	Democratic Republic of the Congo
ci	Côte d’Ivoire
cm	Cameroon
et	Ethiopia
ga	Gabon
gh	Ghana
gm	Gambia
gn	Guinea
ke	Kenya
lr	Liberia
ls	Lesotho
mg	Madagascar
ml	Mali
mw	Malawi
mz	Mozambique
na	Namibia
ng	Nigeria
rw	Rwanda
sl	Sierra Leone
sn	Senegal
sz	Eswatini
td	Chad
tg	Togo
tz	Tanzania
ug	Uganda
za	South Africa
zm	Zambia
zw	Zimbabwe

A. Introduction

A.1. The role of education in economic development

"Education is the most powerful weapon, which you can use to change the world and no country can really develop unless its citizens are educated."

Nelson Mandela

With these inspiring words from Nelson Mandela, I would like to introduce the following three chapters of my doctoral dissertation titled *"The Underlying Role of Education, Gender Inequality and Health in Economic Development: Sub-Saharan Africa, 1920-2013".* Indeed, education is in every sense one of the essential factors for development and a key driver to tackle many of the challenges faced by people in the developing world. It provides the tools to a host of benefits for the individual and society as a whole, including improved quality of life, better health, increased wellbeing, and higher productivity, thus fostering social as well as economic advances.

Scholars have investigated the link between education and economic progress, but also development in terms of health and wellbeing. The necessity to account for human capital in economic growth and development analyses emerged only during the 1960s and 1970s (e.g., Becker 1962, 1975). From a theoretical perspective, endogenous growth theory models (e.g., Lucas 1988; Mankiw et al. 1992) discuss the importance of education for both individual human capital and socio-economic development, having positive effects on poverty mitigation, creating opportunities in the labor market and thus promoting socio-economic growth. Nelson and Phelps (1966) and Romer (1989, 1990) hypothesize that for the achievement of economic growth via technological change, it is essential for a country to engage in innovation and imitation activities, in which human capital constitutes a major input.

Empirically, Hanushek and Woessmann (2008) confirm these theoretical considerations, concluding that human capital is an important input in the production process and a primary source of productivity growth. This implies that improving education in terms of quantity and quality is crucial for fostering development in any region. Kim and Terada-Hagiwara (2013), focusing on Asian countries, argue that education is the initial step along the process of economic development in emerging regions. Other studies (e.g., Mamoon and Murshed 2009; Faria et al. 2016) discover that the accumulation of human capital stocks might foster economic development through better functioning institutions and improved policy usage like trade liberalization. Moreover, Weiss (1995) investigates the link between education and income in developing countries at the individual level and finds that better educated individuals have a higher earning potential that contributes to an improved quality of life compared to those with lower educational attainment. Blankenau et al. (2007), basing their analyses on developing countries, find a positive correlation between education expenditures and long-term economic growth when government budget constraints are taken into account. Similarly, Gyimah-Brempong et al. (2006) discover that all levels of educational attainment including primary, secondary, and tertiary education have a positive and significant effect on per capita income growth in African countries. This is only a small selection of the numerous studies, which investigate the role of human capital in economic development. Yet, they conclude unanimously that education is crucial for increased economic performance in both developing and developed countries, and that nations fail without investment in human capital.

More specifically, education is also a fundamental social determinant of health, which is another key aspect of economic development. Over time, educational attainment, in particular years of schooling, has become a widely considered indicator of socio-economic status. Its well-established relationship with health has been examined by a significant number of studies (e.g., Ross and Wu 1995; Rudd et al. 1999; Lawrence et al. 2016; Allison et al. 2019). While health certainly is a prerequisite for learning and absorbing education, formal education is also a contributing cause to health. It teaches people to use their minds and enhances a sense of personal control that encourages and enables a healthy lifestyle. Evidence shows that higher educated individuals with sound self-control are more likely to adopt preventive health behaviors such as exercising, moderate alcohol consumption, and smoking. In addition, they have better self-rated health and lower mortality rates than people who lack education (Seeman and Lewis 1995; Cutler and Glaeser 2005; Mirowsky and Ross 2008; Cutler and Lleras-Muney 2010). Better educated individuals, in fact, tend to be active and effective agents in their own lives, seeking information, which allows them to improve their health (Mirowsky and Ross 1998, 2005, 2017). Moreover, education may protect from diseases by enhancing thinking, reasoning, and problem-solving abilities, as well as the adaption of appropriate prevention and treatment-seeking behaviors (Hahn and Trueman 2015), which is especially important when addressing preventable and curable infectious diseases such as malaria.

While years of schooling is a commonly used indicator, a growing number of studies have focused on literacy as an outcome measure to estimate the relationship between education and health (e.g., Grosse et al. 1989; Baker et al. 1996, 1997; DeWalt et al. 2004, 2005; Paasche-Orlow and Wolf 2007; Berkman et al. 2011). Patients' literacy is notably crucial to access and understanding important health-related information such as medical prescriptions, instructions for care, disease prevention, and treatment-seeking options. In addition, oral language skills are important in medical care settings when it comes to, for instance, the description of symptoms, which will subsequently influence the doctor's capacity to make a diagnosis. Despite emerging discussions on the separation between health literacy and health numeracy, the relevance of numeracy skills for health-related decisions and tasks is still understudied (Rothman et al. 2008). However, evidence leaves no doubt about the importance of an educated society for improved health and other socio-economic development outcomes.

A.2. Inequality as a barrier to development

While efforts in promoting gender equality have made substantial advances in raising awareness and bringing forth change, there is still a long way to go. Particularly, in the education sector, girls continue to face substantial institutional, social, and cultural barriers that prevent them from accessing schooling and learning opportunities. This might not be without consequences for an economy's progress.

From a historical perspective, the world underwent a substantial schooling revolution during the 20th century leading to higher enrollment rates at the primary school level and rising literacy rates worldwide, as well as expansion in secondary and tertiary education (Roser and Ortiz-Ospina 2016). Globally, gender equity in primary education increased from 56 to 65 percent between 1995 and 2018, from 45 to 51 percent in terms of lower secondary schooling, and from 13 to 24 percent in upper secondary education (UNESCO 2020a). By 2020, the literacy rate among the population aged above 15 years had reached 83 percent for women and 90 percent for men, a differential of 7 percentage points. Among individuals aged between 15 and 24 years, gaps in literacy accounted for 2.1 percentage points, and for the elderly, aged above 65 years, 11.5 percentage points (UNESCO 2021).

Although numeracy is at least as important as literacy for health-related activities and economic development in general1 (Hanushek and Woessmann 2012), it has been evaluated much less than literacy in part due to a shortage of data. However, based on the age heaping method, indirect estimates of basic numeracy can be retrieved, showing a consistent correlation with other education measures (A'Hearn et al. 2009; Crayen and Baten 2010; Tollnek and Baten 2016; UNESCO 2021).

Despite this global progress in education, some regions, in particular sub-Saharan Africa, have been lagging behind, in terms of educational achievement, as well as in reaching gender equality in schooling. Although primary school enrollment rates in sub-Saharan Africa increased from 6 percent in 1910 to 78 percent in 2018 (Barro and Lee 2015; UNESCO 2020a), there are still countries in which the literacy rate is below 50 percent among the youth (Roser and Ortiz-Ospina 2016). In terms of educational gender inequality, 12 (15) out of 17 (20) countries worldwide, in which gender disparities still exist in primary (secondary) schooling, are situated in sub-Saharan Africa (UNESCO 2020b).

Findings of the extant literature show that a high degree of gender inequality in education does not only exert detrimental effects on economic development but that, in turn, investment in female secondary education is positively associated with economic growth (e.g., Hill and King 1995; Dollar and Gatti 1999; Knowles et al. 2002; Klasen 2002; Dauda et al. 2013; Oztunc et al. 2015). In addition, higher levels of women's educational attainment have been found to be positively associated with educational outcomes of the next generation (Mare and Maralani 2006), and declines in fertility (Kim 2016) and child mortality rates (Anyanwu et al. 2009). They also lead to greater bargaining power of women within the household, influencing children's health and nutritional status, among other outcomes (Lépine and Strobl 2013), and are further associated with improved female political participation and positions of leadership (Goetz 2003).

Education has indeed the potential to contribute to better socio-economic outcomes and to act as a starting point and pathway towards greater gender parity in a wide range of fields, yielding social and economic benefits through the empowerment of women. To date, activists, practitioners, and scholars have worked together on promoting the consideration and inclusion of women in development cooperation and policies. Influential studies, like Esther Boserup's

[1] Numerical abilities are notably important for production, trade, agriculture, or even household activities (Tollnek and Baten 2017). In addition, basic numeracy skills are also essential for health-related tasks, which frequently require a sense of proportion and time.

work on the role of women in economic development, have emphasized the interrelationship between the socio-economic progress of a nation and the role of women in society (Boserup 1970). Her research highlighting women's position in developing economies and their economic contributions has served to convince nongovernmental organizations and development planners to integrate women into their projects, pleading for greater gender equality.

A substantial body of research, as well as practical experience, suggest that the empowerment of girls and women is not only crucial on intrinsic grounds, but that gender equity cannot be separated from other important aspects of development such as education, health, socio-economic rights, and even economic progress.

A.3. Aim and outline of the dissertation

While the complex relationship between education, gender inequality, health, and economic advancement has been studied extensively, a comprehensive long-term perspective is missing. Yet, this is non-negligible for obtaining a holistic view on sustainable development, especially in developing countries. Hence, this doctoral dissertation aims to provide insights into the evolution of Africa's human capital. In particular, this thesis examines the patterns of numeracy and literacy, the trajectories of gender disparities in schooling and their determinants, as well as the role of education in preventive health care and economic development. The birth cohort approach applied in all three chapters of this dissertation allows to investigate the above-mentioned development aspects across cohorts and over time, covering most of the 20th century. The chosen region of study is sub-Saharan Africa, a part of the world where the right to education, especially for girls, continues to be a challenge, the spread of infectious diseases severely affects people's lives and the prospects of economic development remain bleak.

In the first chapter, titled *"Educational Gender Inequality in Sub-Saharan Africa: A Long-Term Perspective"*, I investigate together with my co-authors Joerg Baten, Michiel de Haas, and Felix Meier zu Selhausen the evolution of educational gender inequality patterns across sub-Saharan African countries and districts as well as in comparison with other world regions over the 20th century. Based on our descriptive statistics, we find that sub-Saharan Africa, relative to other developing regions including South Asia, Southeast Asia, and the Middle East and North Africa (MENA), displays the lowest educational gender inequality gaps in the beginning of the 20th century, which can be associated with its comparatively low educational level. During the colonial period, however, we observe a rise in educational gender disparities in all world regions. Sub-Saharan Africa's tilting point in the 1960s was later than in other regions, and by the 1980s sub-Saharan Africa had the highest gender disparities. Within Africa, we observe a similar trend across most countries, with a widening of the gender gaps in education during the colonial era (c.1880-1960), peaking mid-century, followed by a consequent decline during independence in the post-colonial period. We find that men's educational progress is correlated with an initial increase and subsequent decline of the educational gender gaps. We refer to this pattern as the *educational gender Kuznets curve*. Based on six decadal cohorts and 1,177 birth districts, we employ a Least Squares Dummy Variable model and investigate correlates of educational gender inequality at a sub-national level. Our regression results support the inverted U-shaped relationship between the gender gap and male education. In addition, we find that gender gaps in educational attainment were lower in districts that had early access to railroads, more urbanization, coastal location, and early 20th century mission stations.

The second, single-authored chapter, titled *"Educated Girls, a Force for Development? Gender Inequality in Education and Economic Performance in Sub-Saharan Africa: A Path-Dependency Analysis",* explores the association between educational gender inequality and economic growth. This persistence study applies a repeated cross-sectional regression design and examines the effects of path dependency in education on current per capita economic output. Based on a sample of 19 sub-Saharan African countries, 1,107 sub-national regions, six decadal birth cohorts, and a total of 5,322 observations, results show a strong negative correlation between gender disparities during the past century and current economic activity, proxied by nighttime light intensity per capita. Moreover, they reveal that increased investment in female education would likely have benefited sub-Saharan Africa's economic output per capita. Investigating indirect effects, findings of the applied mediation analysis show that part of the negative association between gender disparities in education and economic development is mediated through fertility. Finally, a number of control variables, including educational expansion, trading location, access to railroads, the endowment of minerals, labor migration, and to some extent democracy and life expectancy at birth, are positively correlated with economic development.

In the third and final chapter, titled *"Uncovering the Role of Education in the Uptake of Preventive Measures against Malaria in the African Population"*, which I co-authored with Neha Upadhayay, we look at the role of education, in particular numeracy and literacy, in malaria prevention and treatment-seeking behavior adopted among the African population. We base our pooled OLS analysis on a sample of 33 African countries, 407 regions, and a total of 1,960 observations covering six birth decades (1940s-1990s). Findings show that being numerate and literate are both positively correlated with our measures for malaria control, including the usage of insecticide-treated bednets, the intake of antimalarial drugs and treatment-seeking in a medical facility, in case of malaria symptoms. Standardized coefficients suggest that numeric skills are at least as important as being literate. Keeping in mind that malaria prevention, and treatment-seeking attitudes are influenced by unobservable factors that we cannot account for, we control for relevant factors including gender, socio-economic status, topology, and urban-rural settings. Results suggest that, besides education, the involvement of women in healthcare decision-making and the exposure to media are positively associated with preventive attitudes and treatment practices. On the opposite, we find that having a low socio-economic status is negatively correlated with malaria control. Similarly, in higher elevated regions and areas with lower precipitation, where malaria is less prevalent, the usage of malaria protection measures is low. However, in urban regions, antimalarial drugs are frequently used as a measure of protection although the disease is spread more severely in rural regions.

The contributions to literature are several-fold. First, this thesis adds to a growing body of literature on tracing Africa's expansion of educational attainment, which up to now has mostly concentrated on males (Frankema 2012; Cogneau and Moradi 2014; Dupraz 2019; Juif 2019; Alesina et al. 2021; Cappelli and Baten 2021). In that sense, the first chapter explores long-term trends of gender disparities in educational attainment as well as their correlates across countries and regions. Second, to the best of my knowledge, this dissertation is the first to analyze the link between historical gender differences in educational attainment and current economic outcomes in sub-Saharan Africa at a regional level, pointing out that history matters and path dependency plays a role. Third, it brings forth an extension of available data on various malaria control indicators and contributes to the literature by providing a holistic and detailed view on malaria prevention and treatment-seeking behavior across the majority of African countries at a regional level. Moreover, while research so far provides information on the relationship between educational attainment, literacy, and behavioral aspects of malaria control, this thesis investigates in addition, the role of numeracy skills in this context.

Based on findings in the literature the vital role of education in society and its importance for health and sustainable long-term development cannot be denied. Over the past century, major global progress was made towards increasing access to education. However, in sub-Saharan Africa, which has the highest school exclusion rates worldwide, the right to education remains a challenge, especially for girls. Together, the following chapters, therefore, make a first attempt in assessing long-term differences in educational attainment between boys and girls, provide important insights on how these act as a barrier to economic development in sub-Saharan Africa and emphasize the essence of numeracy and literacy for the adaption of correct malaria prevention and treatment-seeking behavior.

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B. Educational Gender Inequality in Sub-Saharan Africa: A Long-Term Perspective

Abstract

To what extent did sub-Saharan Africa's 20th century schooling revolution benefit boys and girls equally? Using census data and a cohort approach, we examine gender gaps in years of education over the 20th century at world region, country, and district levels. First, we find that compared to other developing regions, Africa had a small initial educational gender gap but subsequently made the least progress in closing the gap. Second, in most of the 21 African countries studied, gender gaps increased during most of the colonial era (ca. 1880-1960) and declined, albeit at different rates, after independence. On the world region and country level, the expansion of men's education was initially associated with a growing gender gap, and subsequently a decline, a pattern we refer to as the *educational gender Kuznets curve*. Third, using data from six decadal cohorts across 1,177 birth districts, we explore sub-national correlates of educational gender inequality. This confirms the inverse-U relationship between the gender gap and male education. We also find that districts with railroads, more urbanization, coastal location, and early 20th century Christian missions witnessed lower attainment gaps. We find no evidence that cash crop cultivation, agricultural division of labor, or family systems were linked to gender gaps.[2][3]

[2] This chapter was co-authored with Joerg Baten, Michiel de Haas, and Felix Meier zu Selhausen and published in the Population and Development Review (2021). I contributed approximately 40% to this research paper.

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B.1. Introduction

While sub-Saharan Africa (SSA) has a poor and erratic record of economic growth over the long 20th century, its sustained expansion of education is beyond dispute. Primary school enrollment rose from 6 percent of school-aged children in 1910 to 78 percent in 2018 (Barro and Lee 2015; UNESCO 2020). Average educational attainment increased from 0.2 years of schooling in 1900 to 2.3 in 1970 and 5.7 in 2010 (Barro and Lee 2015). Despite this significant progress, SSA's educational expansion was highly uneven, with certain regions and particular sections of the population benefiting earlier and more than others.

Gender was a major fault line, as boys benefitted disproportionally from emerging educational opportunities. In many developing countries women have caught up and sometimes even today outperform men in terms of school attainment (Grant and Behrman 2010; Psaki et al. 2018; Bossavie and Kanninen 2018). SSA, however, not only exhibits the lowest level of education worldwide[4] but also the highest degree of schooling inequality in favor of boys (Psaki et al. 2018; UNICEF 2020). Twelve (15) out of the 17 (20) countries in the world where girls have not yet caught up with boys in primary (lower secondary) school enrollment are located in SSA (UNESCO 2020).

Gender equality in education has been linked to a great variety of favorable outcomes for women, their households, and for society as a whole. Such positive outcomes include women's economic and political participation later in life (World Bank 2017), lower fertility, and reduced incidence of early marriage (Lloyd et al. 2000; Duflo et. al. 2015; Adu Boahen and Yamauchi 2018; Kebede et al. 2019), reduced child mortality (Makate and Makate 2016; Keats 2018; Andriano and Monden 2019), improved family well-being (Abuya et al. 2012; Pratley 2016), and economic growth (Klasen 2002; Baliamoune-Lutz and McGillivray 2009; Klasen and Lamanna 2009). It is thus crucial to understand the origins and drivers of African women's educational attainment relative to men's.

In this article, we trace and take a first step towards exploring and explaining gender inequality in education across SSA over most of the 20th century – thus covering the rise of African mass-education. To trace educational gender inequality over time, we rely on census data and apply a cohort approach, selecting individuals aged 25-80 years. We assign men's and women's acquired years of education to their region, country or district of birth. We reconstruct

[4] SSA has the highest rate of exclusion, with 19 percent (37 percent) of primary (lower secondary) school-age children being denied the right to education (UNESCO 2020).

the absolute gender gap in years of education covering approximately 15.8 million individuals across 21 countries and 1,177 districts.

Gender gaps are obviously shaped by policy decisions on the national level. However, since they are also highly heterogeneous within individual countries, it is important to explore sub-national variation. While existing datasets (e.g., Barro and Lee 2013; Lee and Lee 2016) provide time series of educational attainment of men and women at the country-level, the use of individual-level data enables us to also investigate historical educational gender gaps in Africa at the sub-national level. Our regression analysis does not identify causal relationships but rather explores relevant initial and dynamic local conditions that plausibly contributed to educational gender inequality in the long-run, including religion, agriculture, family systems, urbanization, and educational expansion. Unlike earlier “persistence” studies that have linked historical determinants, such as Christian missionary presence (Nunn 2014; Montgomery 2017) or colonial cash crop agriculture (Miotto 2019), to present-day gender-biased education outcomes in SSA, our paper offers a dynamic perspective, showing that gender gaps shifted significantly over the 20th century. In our regional analysis, we control for spatial autocorrelation (Kelly 2019).

We analyze gender gaps at three levels of aggregation. First, we place Africa’s trajectory into perspective by comparing SSA to South Asia, Southeast Asia, and the Middle East and North Africa (MENA). In each region, we find that the educational gender gap first rose and subsequently declined over time as male education expanded, a relationship that we refer to as the *educational gender Kuznets curve.* While SSA’s progression to gender equality was the slowest over time, SSA also had the lowest level of educational gender inequality at each level of male educational expansion. This leads us to conclude that Africa’s comparatively gender unequal outcomes today are linked to its lower levels of overall educational expansion, rather than region-specific gender biases. Second, we compare long-term trajectories of the educational gender gap across African countries. We document significant cross-country heterogeneity. Most former French colonies progressed slowly in closing the gender gap in educational attainment, which we link to their slower overall educational expansion. Southern Africa’s gender gaps were remarkably small. Third, we analyze gender gaps at the district level for three periods (1920-1939, 1940-1959, 1960-1979), using decadal birth cohorts. We explore various initial and dynamic factors associated with gender gaps. We find that districts with large cities, coastal location, and railroad connection had significantly lower educational gender inequality. We also find that districts treated by intensive and early Christian missionary activity witnessed lower educational gender inequality. We do not find evidence that agricultural practices, such as cash crop cultivation, were significantly associated with gender gaps.

Our study makes a contribution at the intersection of two empirical literatures on schooling outcomes. First, we relate to a thriving empirical scholarship on long-term patterns and determinants of gender differences in educational attainment in Europe and the US (Goldin et al. 2006; Becker and Woessmann 2008; Bertocchi and Bozzano 2016; Baten et al. 2017), Latin America (Duryea et al. 2007; Manzel and Baten 2009), and Asia (Friesen et al. 2012).[5] Second, we contribute to an expanding literature that traces colonial Africa's expansion of formal education, human capital formation, and educational mobility, which has so far focused primarily on boys and men (Frankema 2012; Cogneau and Moradi 2014; Dupraz 2019; Juif 2019; Alesina et al. 2021; Cappelli and Baten 2021).

There are some studies at the intersection of these two literatures, looking at trends in African gender gaps. Alesina et al. (2021, Figure 3) examine intergenerational mobility in education for 26 African countries, 1960s-1990s, reporting lower mobility for girls in the Sahel region. Barro and Lee (2015, Table 2.10) present decadal female-male ratios of years of schooling (1870-2010) for SSA as a whole. Cogneau and Moradi (2014) measure boys-girls enrollment ratios for colonial Ghana and Togo for several reference years. Evans et al. (2021) as well as Psaki et al. (2018) trace gender attainment and enrollment gaps across middle- and low-income countries, from 1960-2010 and 1997-2014 respectively. Meier zu Selhausen (2014), Meier zu Selhausen and Weisdorf (2016) and De Haas and Frankema (2018) trace gender gaps in colonial and post-colonial Uganda. Our study further advances this literature by tracing and interpreting gender gaps over the 20th century continent-wide, and in a large number of countries and sub-national regions across SSA.

We also contribute to a diverse body of studies that explore correlates and drivers of educational gender gaps across countries and regions. Some studies have linked educational gender inequality to structural differences between spatial units. For example, Norton and Tomal (2009), Izama (2014) as well as Alesina et al. (2021) compare gender gaps between Muslims and Christians. Nunn (2014) and Montgomery (2017) show positive effects of historical Protestant and Catholic missionary presence on educational gender equality today. Miotto (2019) finds that colonial legacies of cash crop farming are linked to better female educational outcomes today, while Ashraf et al. (2020) have linked the cultural practice of bride

[5] See Bertocchi and Bozzano (2020) for a survey of this literature.

price to lower educational gender inequality. Others, in contrast, have emphasized that gender gaps are dynamic within spatial units over time, and endogenously linked to processes of economic change and educational expansion itself. Both Psaki et al. (2018) and Evans et al. (2021) stress that a country's stage of educational development provides critical context for evaluating progress in achieving gender parity in years of education. Studies on contemporary gender gaps similarly observe rapid narrowing or even reversal of gender gaps in developing countries, which attests to their dynamic nature (Grant and Behrman 2010; Jones and Ramchand 2016).

"Local-structural" and "temporal-dynamic" explanations of gender gaps are not inconsistent with each other, but place different emphasis and have divergent policy implications. If gender gaps are primarily dynamic, the implication is that they can be best resolved through investment in overall educational expansion. If they are structural, region-specific biases toward female education should be identified and tackled. Our multi-level and long-run study design allows us to analyze these different types of explanations jointly. On the one hand, we find that gender gaps are highly dynamic, following an inversely U-shaped trajectory as educational attainment expands. On the other hand, we unpack the structural forces that are associated with the magnitude of gender gaps along such trajectories in some countries and districts compared to others, such as missionary exposure and urbanization. The next section justifies the inclusion of various correlates and states our expected findings, based on theory and earlier empirical studies.

The paper proceeds as follows. We first expand on the theory and previous empirical literature that shaped the scope of our investigation. Second, we present the data and method. Third, we (i) compare long-term patterns of educational gender inequality in SSA with other colonized world regions where mass education expanded over the 20th century, (ii) analyze country trajectories in SSA (iii) explore various initial and dynamic factors on Africa's sub-national level that are associated with educational gender inequality 1920-1979 in a multivariate regression framework. Finally, we discuss those findings.

B.2. Educational gender inequality in Africa: theory and literature

B.2.1. Educational expansion

Based on educational attainment from the 1960s onwards, Evans et al. (2021, 7) find that absolute gender gaps in education "often got worse before they got better," as overall educational attainment increased from very low levels. However, evidence on such inverse U-shaped trajectories of gender gaps in Africa before 1960 is limited, despite the fact that many African countries had witnessed substantial educational expansion by this time. Based on data on male and female literacy and numeracy as well as occupational status and marriage ages of Christians in and close to Kampala (Uganda), Meier zu Selhausen and Weisdorf (2016) observe an educational gender Kuznets curve between ca. 1900 and 1960, peaking in the 1920s. Based on more representative census data on numeracy, literacy, and years of education, De Haas and Frankema (2018) confirm this inverse U-curve over time, but date its peak much later, during the 1950s, just before independence.

In this paper, we further investigate this educational gender Kuznets curve. Most importantly, we hypothesize that regularities in the trend of attainment gender gaps are not primarily linked to time, but to the expansion of (male) education. As has been shown across various societies, including in Asia (Friesen et al. 2012) and Latin America (Manzel and Baten 2009), boys tend to accumulate substantially more years of education than girls in the early stages of educational expansion. Consequently, they develop an increasing educational lead over girls. At some point, as most boys have attained a certain amount of schooling, demand for further male education begins to diminish. The level at which this occurs depends on labor market dynamics and skills demand, which differed across time and space in SSA (Frankema and van Waijenburg 2019). All the while, schooling opportunities for girls continue to expand, resulting in a reduction of the gender gap. Rising attainment inequality between men and women may also be slowed down and eventually reversed when too much gender inequality is considered undesirable from a labor market and marriage market perspective (Meier zu Selhausen and Weisdorf 2021). The flattening off and subsequent reversal of the attainment gender gap is at least partially driven by educational expansion itself, as educated fathers tend to see value in girls' education and are therefore more likely to send their daughters to school (Coquery-Vidrovitch 1997:151; De Haas and Frankema 2018; Meier zu Selhausen and Weisdorf 2016, 2021).

Our key interest is to compare African educational gender Kuznets curves with other world regions, across African countries, and across sub-national regions. We not only expect to find such curves, but also seek to exploit variations in the timing of their peaks, both in time and along educational expansion trajectories, to obtain a better understanding of the extent to which local and structural factors, such as cultural attitudes and colonial legacies, are associated with educational gender inequality. We expect that the educational gender Kuznets curve itself accounts for a substantial share of the variation in gender gaps observed over time and at our three different levels of observation.

B.2.2. Openness

During the 20th century, SSA experienced a dramatic increase in outward orientation, both in terms of trade integration with world markets and exposure to new cultural, religious, and social influences (Cooper 1981, 2014; Bayart and Ellis 2000). This process, which we refer to as "openness," was spatially uneven.[6] Coastal, urban and railroad-connected areas were exposed sooner and more intensely. We expect that more open regions are associated with lower gender inequality in education. Trade and urbanization generated new income opportunities and resulted in greater demand for labor in urban areas, quelling anxiety among men about female competition for jobs and creating incentives to extend education to women (Elkan 1957; Boserup 1970; de Haas and Frankema 2018). Moreover, new occupational strata, family arrangements, and "modern" identities emerged in urban areas over the colonial era (Elkan 1960; Meier zu Selhausen et al. 2018). Cities were often hubs of early educational expansion for men and also attracted educated labor migrants, who were subsequently more likely to send their urban-born daughters to school. Such demand for female education was met by supply, as urban areas were typically the first to cater for female secondary education and increasingly provided administrative, teaching, and nursing jobs from the late colonial era onward (Obbo 1980; Leach 2008; Meier zu Selhausen and Weisdorf 2021). Railroads, built to connect mines and cash crop regions to ports, played a crucial role in connecting remote rural areas in the interior to coastal urban areas. Moreover, urban agglomerations themselves tended to emerge along railroads, an effect that persisted even as, after independence, railroads lost their colonial function (Jedwab and Moradi 2016; Jedwab et al. 2017).

[6] We derive the use of the term "openness" from economics, where it is typically associated with trade. See for example Edwards (1998) and Stulz and Williamson (2003).

B.2.3. Colonizer identity

Several historical studies have found uneven educational expansion across colonizers; in particular, lower enrollment in French than British colonies (Frankema 2012; Cogneau and Moradi 2014; Dupraz 2019; Guarnieri and Rainer 2021). As overall educational expansion progressed more slowly in French colonies, we should expect (former) French colonies to occupy earlier stages of the educational gender Kuznets curve than their (former) British counterparts. If we follow the inverse U-shaped logic of the curve, this implies that French colonies initially should have had smaller gender gaps than British colonies, but also experienced a widening of their gender gaps as education expanded in the post-colonial period from very low levels while (former) British colonies had already reached their attainment gap peak and were on a trajectory towards lower educational gender inequality. At the same time, we have no reason to expect different degrees of structural gender bias among colonizers. Thus, we should expect gender gaps to be similar at each level of male educational expansion (i.e., along the educational gender Kuznets curve). Potentially, mandated territories (former German colonies) had smaller gaps than colonies proper, since they had to report educational statistics to the League of Nations, a modicum of accountability towards the international community that may have been associated with better educational outcomes for girls (Pedersen 2015, 134). We are agnostic about the trend of the gender gap in countries that were not or only briefly colonized (Ethiopia and Liberia, in the case of SSA).

B.2.4. Religion

Christian missions provided the bulk of formal education in colonial Africa, particularly in British colonies and especially before the 1930s (Frankema 2012; Meier zu Selhausen 2019). Various studies have observed substantial positive effects on local contemporary educational outcomes of missionary activities during early colonial times (Gallego and Woodberry 2010; Wantchekon et al. 2015; Jedwab et al. 2022; Alesina et al. 2021; Cappelli and Baten 2021). Historians have suggested, though, that missionaries promoted patriarchal social order, and disproportionally allocated educational resources to boys (Egbo 2000; Kyomuhendo, McIntosh and McIntosh 2006; Hanson 2010). As a result, girls received not only fewer years of education, but also lower quality, which further disincentivized parents to educate their daughters, although female missionaries may have more actively promoted girls' education.

Nevertheless, there is a substantial literature that argues for a positive association between missionary schooling, especially by Protestants, and female educational advancement and gender equality in education. Nunn (2014) finds that Protestant missionary exposure in early colonial Africa is associated with more female years of education today, while Catholic missionary exposure is associated with greater male educational attainment. Montgomery (2017) establishes a positive effect of both Protestant and Catholic missions on male and female years of education in Tanzania, but like Nunn (2014) observes that Protestant missionary legacies are linked to smaller present-day gender gaps, while Catholic missions are linked to larger gaps.[7] At the same time, it has been argued that the Catholic tradition of gender-segregated schooling made girls' attendance more palatable to conservative parents, and increased their educational attainment, at least quantitatively (the curriculum would still be focused on religious devotion and domesticity) (Coquery-Vidrovitch 1997: 155). Based on these previous findings and considerations, we expect consolidated missionary presence to be associated with smaller educational gender gaps. We also expect Protestant missions to be more strongly associated with gender equality.

Large regions of Africa, especially the West African interior and East African coast, have deep Islamic roots which predated European presence. In many Islamic areas, colonial governments and Christian missionaries played only a marginal role in the provision of education. As a result, Muslims tended to have lower educational attainment than their Christian counterparts, both within and across countries (Izama 2014). Based on the analysis of global data, Norton and Tomal (2009) conclude that Islam on average exerts a negative influence on female schooling. However, detailed case studies on pre-colonial Sokoto Caliphate Nigeria (Boyd and Last 1985) and colonial Zanzibar (Decker 2006) have shown that Islam cannot be considered uniformly incompatible with female education. Moreover, Coquery-Vidrovitch (1997, 151) points out that African Muslims sent their children to public rather than missionary schools, which may have affected girls' opportunities more than religion per se. Globally, cross-country regressions including countries with large Muslim populations fail to find a statistically significant effect of Islam on the educational gender gap for birth cohorts aged 25–34 in 2010 (McClendon et al. 2018). While Islam is a relevant variable to explore, we acknowledge its heterogeneous nature across Africa, pointed out in previous literature, and do not expect it to be associated with the size of gender gaps as long as we control for male education (the Kuznets curve effect).

[7] For India, Lankina and Getachew (2021) associate Christian missionary activity with higher female literacy during colonial and post-colonial eras. Calvi et al. (2020) show that this relationship is particularly strong for missions with greater female missionary staff presence.

B.2.5. Agriculture

We consider three dimensions of agriculture. First, we examine cash crops and gender gaps. Cash crops were central to African colonial economies, and are associated with sharp spatial inequalities, past, and present (Roessler et al. 2020). Even if cash crops expanded economic opportunities, it has been argued that their introduction also undermined the status of women, as men tended to control most cash crop income, while women were pressured to provide increased non-remunerated agricultural labor inputs. Such dynamics were reinforced by colonial authorities who focused their efforts to promote cash crops on men and treated women and children as “family labor” (Boserup 1970; Whitehead 1990; Byfield 2018). Rising opportunity costs of going to school in a context of increased demand for agricultural labor may have reduced girls’ access to school and widened educational gender gaps. More indirectly, women’s loss of status, power, and economic autonomy associated with cash cropping under colonial rule may have reduced the perceived value of girls’ skills accumulation and thus demand for education, further compounding educational gender gaps. Nevertheless, Miotto (2019) reports a positive long-run effect of colonial-era cash crop agriculture on women's status today, measured as household bargaining power, less willingness to justify husbands' violence, and higher levels of education. She argues that this effect is driven by increased female labor force participation in the cash crop economy, which benefited girls’ education. However, Miotto does not address attainment gender gaps per se. In sum, we expect cash crop regions to exhibit larger education gender gaps.

Second, we explore spatial variation in pre-colonial gender division of labor in agriculture. In her landmark study, Ester Boserup (1970, 16) posited that “Africa is the region of female farming par excellence.” However, she also noted that there was considerable variation in terms of male and female roles in agriculture across African societies, a point that has been emphasized by other scholars as well (Baumann 1928; Whitehead 1990; Alesina et al. 2013). The agricultural division of labor may have affected educational gender inequality. Boserup herself argued that traditional agricultural practices play a crucial role in shaping societies’ variation in gender roles more broadly, reasoning that women’s lack of participation in agriculture resulted in the development of unequal gender norms, relegating women to domestic duties and seclusion. The clearest example of such a practice is plough-based agriculture, which historically relied on upper body strength (male task) and required less weeding (female task). Studying the long-run effects of traditional plough use on gender norms and female labor force participation in a global context, Alesina et al. (2013) find evidence for this theory.

Following Boserup (1970), we may expect that the more involved women were, the more equal gender norms emerged and the smaller educational gender inequality was. Conversely, one might argue that the opportunity cost of girls' education was higher in female farming systems, which would reduce their participation in education. Based on these considerations, we expect lower gender inequality in female farming systems, but also that this effect is negated in regions that were deeply involved in cash crop production, which increased the opportunity cost of girls' education.

Livestock-oriented societies in eastern and southern Africa tended to be deeply patriarchal, valuing male hunting and herding activities over female domestic ones (Coquery-Vidrovitch 1997). However, the effect of pastoralism on the educational gender gap is not obvious. On the one hand, we may expect more female seclusion in pastoral societies, as men were primarily responsible for herding and hunting and women tended to stay behind in the compounds. Following Boserup (1970) and Alesina et al. (2013), we would expect this to result in more gender inequality, which may, in turn, translate into a larger educational gender gap. For education, however, a specific opposite mechanism may counteract this: boys' absence from home and a culture that glorified livestock and discounted the value of modern education for the most valued members of society may have produced opportunities for stay-at-home girls to receive (missionary) education. Several scholars have observed that women's relative immobility has resulted in low gender gaps in Southern Africa, Botswana, and Lesotho in particular, where boys were absent herding cattle, as well as engaging in labor migration, leaving girls behind to populate schools (Coquery-Vidrovitch 1997: 148, 154; Stromquist 2007: 157; Mafela 2008: 338). Due to these heterogeneous mechanisms, we do not expect to find a strong correlation between pastoralism and educational gender gaps.

B.2.6. Family systems

Finally, family systems that regulate degrees of female autonomy can also be expected to affect educational gender inequality. Van der Vleuten (2016), for example, finds a strong correlation between the value assigned to women in the family and the educational gender ratio in developing regions during 1950-2005. Bride price, which is a payment at marriage by the groom or his family to the bride's family, gives the latter an incentive to invest in their girls' education (Lowes and Nunn 2018; Ashraf et al. 2020); as opposed to dowry, which is paid by the bride's family. On the other hand, it has been shown that adverse shocks to family income can increase girls' chances of early marriage at the expense of their education (Björkman-Nyqvist 2013; Corno and Voena 2016; Archibong and Annan 2020). Patrilineal systems, where property is passed on through the male line, are likely to see gender discrimination in favor of boys, while matrilineal systems have better outcomes for girls (Holden and Mace 2003; Henderson and Whatley 2014). Polygamy, a long-established practice in most SSA countries (Fenske 2015), is associated with lower female status, in the case of additional wives (United Nations General Assembly 1979). Thus, we expect that family systems that suppress female autonomy, involving dowry, patrilineal inheritance, and polygamy, are associated with larger gender gaps.

B.3. Data and methods

We analyze attainment gender gaps in SSA over the 20th century (i) in a world-region comparative perspective, (ii) at the country level, and (iii) at the sub-national (district) level. Since we are interested in historical changes in gender differences in educational attainment, rather than accumulated human capital of men and women, we do not consider the stock of education in the entire population at a certain moment in time, but instead use a flow approach, tracing the average years of education completed[8] for birth cohorts of men and women per world region, country and district. We then calculate the gender gap in educational attainment by subtracting the average level of educational attainment among women from the average level of educational attainment among men, assuming constant returns to education regardless of the absolute level.[9] Hence, a positive value indicates that men are more educated than women and vice versa. Table B.1 summarizes the geographical scope, data sources, sample sizes, and cohorts as well as units of observation.

B.3.1. Measuring sub-Saharan African gender gaps in a global historical perspective

We compare gender inequality in SSA to other developing regions with similar levels of educational expansion in the 20th century using the dataset by Barro and Lee (2013) that provides world-wide data on male and female years of education completed for 5-year age

[8] Individuals who never enrolled in school are included in our sample and coded as having zero years of education.

[9] The absolute gap is the same if women have 1 year of education and men 2, relative to women 9 and men 10. In the Appendix, we replicate our results using a gender ratio (i.e., ratio of male to female educational attainment), which assumes declining returns to education as the absolute level increases. The ratio is the same if women have 1 year of education and men 2, relative to women 5 and men 10.

cohorts (15-74) for 5-year intervals in the 1950-2010 period, based on census data.[10] Their estimates for each interval are corrected for selective mortality (i.e., educated people may live longer). We use their dataset to trace country-level male and female education back to the early 20th century. To identify the birth year, we consider the year of census enumeration minus the age at enumeration. We transformed the repeated 5-year cohorts in Barro and Lee (2013) into a single 10-year (e.g., 1920-1929) gender gap (i.e., male minus female years of education completed) trend for each country by taking arithmetic averages of the two relevant 5-year cohorts.[11] We then compute regional arithmetic averages on the basis of countries' average educational gender gap, as weighted averages would let South Asia be dominated by India and Southeast Asia by Indonesia. Pre-1890 birth decades were dropped due to potential survivorship bias (as discussed below).

B.3.2. Measuring gender gaps over time in sub-Saharan African countries

Our cross-country analysis of educational gender gaps is based upon aggregated individual-level data, retrieved from IPUMS International (Minnesota Population Center 2019). IPUMS provides 63 harmonized, representative census samples, covering ~10% of country's population on 24 SSA countries between 1960 and 2013. We restrict our sample to the earliest and latest census years for each country recording both age and years of education completed. This leaves us with data from 36 national censuses for 21 countries on about 43 million individuals from Benin, Botswana, Burkina Faso, Cameroon, Ethiopia, Ghana, Guinea, Kenya, Lesotho, Liberia, Malawi, Mali, Nigeria,[12] Rwanda, Senegal, Sierra Leone, South Africa, Tanzania, Uganda, Zambia, and Zimbabwe. As of 2020, those sampled countries were home to about 650 million people, representing approximately 60 percent of SSA's population. We construct the absolute gap between male and female years of education completed, analogous to the world region analysis above, except that we use 5-year birth cohorts here.

To obtain coverage of all cohorts for the 1900-1984 period, and to avoid double counting of individuals observed in consecutive censuses, we only keep the birth decades of the 1900s to 1950s from one early census year and the 1960s and 1970s birth decades from one late census year of each country. For Burkina Faso, Ethiopia, Rwanda, and Sierra Leone we derive all observed birth decades from the only available census year that records individuals' years

[10] Barro and Lee (2013) provide educational attainment data on: SSA (33 countries), South Asia (6 countries), Southeast Asia (10 countries), and MENA (17 countries).

[11] Appendix Figure B.7 reports results using the gender ratio.

[12] Nigeria is an exception, where data come from household surveys 2006-2010.

of education and age at enumeration. Next, we restrict our sample to individuals aged 25-80 years. At age 25, schooling can reasonably be expected to have been completed (Charles and Luoh 2003). We drop individuals older than 80 years due to small cohort sample sizes and the likelihood of the very elderly to have overstated both age and educational attainment (Guntupalli and Baten 2006; Crayen and Baten 2010; Barro and Lee 2013). Table B.5 in the Appendix provides further details on sample construction.

B.3.3. Investigating correlates of educational gender gaps across regions in SSA

For our sub-national analysis, we further refine our sample to countries for which IPUMS also records individuals' birth location. For Nigeria and Zimbabwe, included in the country analysis, no district of birth is reported. Table B.2 provides details on sample construction: census years, birth decades covered and number of regions included. Our final dataset is based on 15.4 million individuals, born across 1,177 districts in 19 SSA countries, retrieved from 32 national censuses.[13] We aggregate individuals' mean years of schooling by decadal birth cohort and sex at the administrative sub-national level, our unit of observation. Because sample sizes shrink considerably when we disaggregate from country to district, we start in 1920, and drop observations in case they are based on less than 30 individuals. The aggregated sample with 5,226 districts allows us then to calculate our dependent variable: the absolute attainment gap (in average years of schooling completed) between males and females per birth region and birth decade.[14]

Our spatial units of observation correspond to either first- or second-level geographic units,[15] depending on their availability in IPUMS-I, and vary across countries (e.g., districts, regions, or circles). For brevity and clarity, we consistently refer to them as "districts." To account for the different sizes of these administrative subdivisions, we use weights for birth regions' population size per birth decade. IPUMS offers an integrated, year-specific geography

[13] Appendix Table B.5 presents details on sample construction: countries included, census years, number of birth regions, total observations, observations aged 25-80, and the share of men and women in the sample. Appendix Table B.6 reports the number of observed districts per country for each time period.

[14] When calculating the ratio in average years of education between men and women, our dataset reduces to 4,924 observations since females did not receive any education in some regions. Therefore, the level of schooling for women is zero within these regions and therefore these observations are not taken into account in the denominator.

[15] Most countries are divided into administrative divisions which have different levels. First-level geography corresponds to the largest administrative subdivisions of a country (e.g., region) whereas second-level geography corresponds to administrative boundaries that are inferior to the first-level administrative divisions and hence constitute a smaller unit (e.g., districts).

variable providing information at the administrative unit level and the corresponding GIS boundary files, which allows us to account for the fact that many territorial divisions change their geographic borders between the two census years that we use for most countries.

To investigate long-run correlates of educational gender gaps, we construct a geospatial dataset of relevant independent variables at the sub-national level relying on multiple data sources. Table B.3 reports the summary statistics.[16]

Male educational expansion. We use data on male years of schooling completed from IPUMS censuses.

Openness. We calculate the share of the urban population (i.e., cities >10,000 inhabitants) per district from OECD/SWAC's (2020) Africapolis database and Jedwab and Moradi (2016). A dummy for the presence of colonial railroads was derived from Jedwab and Moradi (2016). We also compute a dummy if the district contains an ocean coastline.

Colonizer. We create a dummy for colonizer's identity for territories being ruled by the British, the French (reference category), League of Nations mandate, or being independent during the period of observation.

Religion. We construct a dummy for the presence of major Christian missions (Protestant and Catholic) in a district in 1924, based on Roome (1925) and digitized by Nunn (2010). Although widely used to investigate persistent effects of missionary activity,[17] this source has been demonstrated to be incomplete, reporting mostly European missions and thus missing out on large numbers of smaller out-stations, mostly run by African missionaries (Jedwab et al. 2021, 2022). We argue that sub-national regions with a missionary post in 1924 can be considered the early "heartlands" of Christianization in Africa, with the strongest degrees of institutionalization of missionary educational practices, and potentially the largest number of converts in the colonial era, relative to areas without main stations. We also create a dummy for whether Muslims constituted more than 50 percent of each district's population based on individuals' religion (IPUMS censuses).[18]

[16] Appendix Table B.7 reports descriptive statistics for variables included in educational male-female ratio regressions.

[17] Including the effects of missions on present-day women's education (Nunn 2014; Montgomery 2017).

[18] This late 20th century benchmark is likely to represent the situation throughout the entire 20th century, as the arrival of Islam dates back much further than Christianity in most parts of Africa and its diffusion took place long before our first cohort, the 1920s, was educated.

Agriculture. We obtain locations of colonial export crop output from Hance, Kotschar, and Peterec (1961). The source also reports mining output, which we include as a separate variable. We obtain country-level export commodity output from 1920 to 1979 from a range of sources. We express cash crop and mineral output per capita. Details and sources are outlined in the Appendix. Following German ethnographer Hermann Baumann (1928) and Boserup (1970, 18), we distinguish three gender-divided tasks in agriculture: entirely female *(farm female)*, mostly female but with substantial male involvement *(farm shared)*, and mostly male *(farm male)*, including pastoralism (mapped in Appendix Figure B.10). We calculate the log of the relative share of pastureland to cropland in squared kilometers based on Klein Goldewijk et al. (2017).

Family systems. We create an index of three variables that proxy cultural practices regarding low female autonomy, consisting of ethnic groups' (i) absence of brideprice, practice of (ii) polygamy, and (iii) patrilineality based on Murdock (1967). Country-level fertility rates 1960-1979 are taken from World Bank (2021).

B.3.4. Regression analysis

To examine key factors related to the regional differences of gender gaps in educational attainment we use a LSDV (least-squares dummy variables) estimator and estimate the following regression model:

$$Y_{it} = \beta_0 + \beta_1 X1_{it} + \beta_2 X2_i + \beta_3 X3_{it} + \mu_c + \upsilon_{t_t} + \varepsilon_{it}$$

where Y_{it} represents our dependent variable that measures the gender gap in average years of schooling between males and females per district *i* during birth decades *t* ={1920-1939, 1940-1959, 1960-1979}, $X1_{it}$ is our vector of time-variant variables (i.e., male years of education, railway presence, urbanization, cash crop, and mining output), and $X2_{i,}$ stands for time-invariant locational factors (i.e., coastal location, missions, agricultural systems, family systems). $X3_{it}$ captures the effect of our interaction variables. The term μ_c takes into account country fixed effects, υ_t captures time fixed effects, while ε_{it} represents the idiosyncratic error term. Kelly (2019) recently cautioned that many findings using spatial regressions could have arisen from random spatial patterns. We, therefore, control for spatial autocorrelation.[19] Our

[19] Appendix B.8.2. explains in detail the spatial autoregressive (SAR) model.

model does not strictly identify causal effects. Our goal is to uncover a set of factors that based on theory and previous research plausibly correlate with gender inequality and assess their association with education gender inequality outcomes over time.

B.3.5. Data limitations

Our approach has three limitations that should be kept in mind when interpreting the results. First, our main variable, years of education, indicates educational attainment as measured by years in school completed but does not inform about the quality of education, which may vary across space, time, and gender (Psaki et al. 2018). It is also the most generic indicator of educational attainment, not distinguishing between different levels of schooling, and not reporting on grade repetition. Nevertheless, we consider years of education to be the most suitable variable for the purpose of tracing and comparing gender gaps over a long time-period and large geographical coverage, because of its uniquely wide availability and uniformity across countries and sub-national regions.

Second, our approach of back-casting census data may introduce some measurement error. The possibility exists that the more educated may have a better chance of making it into the older cohorts. Such survivorship bias in cohort analysis has been studied in earlier literature, but its magnitude proved to be modest (Guntupalli and Baten 2006; Crayen and Baten 2010; Barro and Lee 2013). As shown in Appendix Figure B.6 survivor bias in our sample is minimal.[20] Moreover, we include only individuals aged 25-80. A related concern is that the earliest cohorts in our analysis are smaller so that confidence intervals widen considerably as we go back in time, especially in our analysis at the sub-national level. Consequently, we drop district-level birth decades pre-1920, due to the small number of observations. From the 1920s onwards, we drop 10-year district-averages in case they are based on fewer than 30 individuals.

Third, we analyze years of schooling by districts of birth rather than residence. The reason for this choice is that an unknown share of residents enumerated in districts at the time of the census will have migrated there at an earlier (unknown) point in their life. Since migration is strongly age-, skill- and sex-selective, the average years of education in districts of residence reflects this compositional effect. Averages in districts of residence would thus tell us little about spatially uneven educational opportunities for boys and girls, but rather about (gender differences in) district-sorting by level of education (Alesina et al. 2021), which is an altogether

[20] The graphs respectively present sampled countries of (a) East, (b) West, (c) Central and (d) Southern Africa

different topic of study. For our purposes, we consider district of birth to be a much more appropriate unit of analysis. Linking individuals to their districts of birth allows us to explore how the local conditions of openness, religion, agriculture, or family systems in which people were born (and raised, in most cases) affected their subsequent educational attainment. Moreover, we may reasonably expect that most people accumulated (most of) their education in their district of birth, even if they ended up migrating at some point in their life. Still, it should be borne in mind that some individuals will have migrated before or during their schooling, (i) moving with parents, or (ii) explicitly seeking educational opportunity (especially at the tertiary level).[21] Strictly speaking, our analysis, therefore, captures gender gaps between boys and girls born in the same district, but not necessarily having completed their full education there.

B.4. Results

This section presents the results of our comparison of educational gender gaps (i) between SSA and other developing regions, (ii) among SSA countries, and (iii) at the sub-national region level, where we use multivariate regression analyses to explore some variables that are plausibly associated with educational gender gaps over time.

B.4.1. Educational gender gaps in comparable world regions

SSA, MENA, South Asia, and Southeast Asia, all experienced a rise in mass-education over the long 20th century from a similarly low initial level and achieved independence from European colonizers during the mid-20th century. While South and Southeast Asia as well as MENA experienced decolonization soon after World War II, most African countries gained their independence almost two decades later, which may have delayed their expansion of education, and therefore also progression through the educational gender Kuznets curve. Otherwise, we do not have reasons to expect gender bias in education to be different in Africa

[21] The magnitude of both types of migration were modest. Especially during the colonial era, young adult men seeking work predominated long-distance migration, while young children and wives typically did not. Moreover, tertiary educational shares (>14 years of schooling) are negligible during all time periods, except for those born in 1960-1979 (5.3 for men and 2.6 for women). Even if we were to assume that during the colonial era to attend secondary schools, rural children had to migrate outside their birth district, the share of boys and girls having attained more than 7 years of education only came to 6.6 and 1.2 percent in 1920-1939 and 16.8 and 6.2 percent in 1940-1959 cohorts respectively (calculations based on IPUMS). Post-independence, secondary schools became more available in rural areas too, making migration less necessary.

compared to the other three regions. In fact, following Boserup, we might expect smaller gender gaps in Africa (and Southeast Asia) compared to MENA and South Asia, due to the predominance of female farming systems. Missionaries' Christianization efforts were also particularly successful in Africa, compared to the other regions, which may have reduced gender gaps by furthering educational expansion. Islam was widespread in all three regions, and, as noted before, likely had heterogeneous impacts.

Gender gap. Figure B.1 presents the unweighted country average of the gender gap for each of the four world regions. It shows that SSA transitioned from being the least gender unequal region during the early 20th century to the most gender unequal by the 1980s, a situation that persists to the present-day (Barro and Lee 2015). Overall, we can see a pattern of rising absolute inequality in each of the four world regions before mid-century, and declining inequality thereafter. Educational attainment in the MENA region started out as relatively gender-equal but saw a rapidly widening gap of more than two years by the 1940s birth cohort, after which equally strong convergence took place. South Asia presents a picture of relatively high gender inequality in education throughout the entire period, with its gap peaking, jointly with MENA, for the 1940s birth cohort. Southeast Asia peaked two decades earlier and exhibits decreasing absolute gender inequality already for those born after the 1930s. SSA has the latest inequality peak, for the 1950s birth cohort, and has achieved the least progress in closing the gap since.[22]

Kuznets curve. Figure B.2 relates the gender gap to the expansion of male education. In all regions, gender inequality over male educational expansion followed the hypothesized inverted U-shape, as the absolute gender gap initially rose and then fell with sustained educational expansion of men. Throughout, SSA's curve was the least gender unequal, starting out, peaking, and ending up at lower levels than the other world regions. When African boys received about one year of education on average, the gap was just under half a year of education (meaning that girls received just over half a year of education on average), compared to just over half a year in the MENA region, and close to a year in South Asia and Southeast Asia. At about 6 years of education, the gender gap was again smallest in SSA, this time trailed by Southeast Asia and, at a larger distance, South Asia and the MENA region. This brings us to an important observation, namely that SSA's comparatively poor progress towards educational gender equality, shown in Figure B.1, is linked to its slower expansion of male education, which

[22] SSA's relative position, moving from least to most gender unequal, is also visible when we take the ratio (M/F) rather than the absolute gap in Appendix Figure B.7.

has not progressed as far along the downward sloping part of the educational gender Kuznets curve as in the other world regions. All the while, because SSA performs relatively well in terms of gender equality at different stages of its male educational expansion, we have no reason to infer that SSA's relatively poor performance in reducing educational gender inequality across time is linked to more severe structural attainment gender bias.

B.4.2. Trends in educational gender gaps in sub-Saharan African countries

How did individual countries perform relative to SSA's regional pattern presented in Figures B.1 and B.2? Figure B.3 presents the gender gap in years of education for 5-year birth cohorts. Figure B.4 presents the gender gap relative to overall male educational expansion (i.e., the educational gender Kuznets curve).[23] For purposes of analysis and presentation, we show country trajectories in four panels, sorted by (i) the height of their gender gap peak being below/at or above the median (2.5 years of education), and (ii) the timing occurring before/at or after the median date (the 1945-1949 birth cohort).

Early and high gender gap peak

Figure B.3(a) shows five countries. Four are British colonies, in West Africa (Ghana), East Africa (Kenya and Uganda), and Southern Africa (Zambia). The fifth is Cameroon, which was initially colonized by Germany, and divided between Britain and France after World War I as a mandated territory (Dupraz 2019). Figure B.3(a) shows that, in each of these countries, gender gaps rose steadily from the first birth cohort observed and peaked in the 1945 cohort, at levels varying between 2.5 and 3.5 years. For those born between 1945 and 1960 (independence), we see a steady decline of the gender gap. After independence, trajectories diverged, as Kenya continued to steadily close its gap, while progress in the other four countries slowed down. Figure B.4(a) relates the gender gap to years of male education. It shows that the five countries moved along the same steady upward slope of the educational gender Kuznets curve until boys reached four years of education. This initial trajectory implies, approximately, that for every 4 years of education received by boys, girls received only 1. From 4 years of male education onwards, this relationship breaks down, as the curve flattens out and then tilts down. Among the five countries, Uganda started bending its curve towards lower gender inequality

[23] Appendix Figures B.8 and B.9 show those trends in educational male-female ratios.

comparatively sooner as male education expanded, while Ghana bent its curve comparatively late along its progression of male education.

Early and low gender gap peak

This second panel comprises six countries: three Southern African countries with remarkably low or even reverse gender gaps in favor of females (Botswana, Lesotho, and South Africa), two former German colonies, which post-1918 were assigned to Belgium (Rwanda) and Britain (Tanzania) under a League of Nations mandate, and Sierra Leone, formerly a British colony. Figure B.3(b) illustrates that countries' performance in closing the gap was heterogeneous. Botswana, Rwanda, and Tanzania had erased a large share of their male educational advantage between 1945 and 1985, while Sierra Leone's gender gap barely closed post-1945. Figure B.4(b) shows that Rwanda, Sierra Leone, and Tanzania initially followed the same Kuznets curve as the countries in the first panel, until men had reached three years of education on average. At this point Rwanda started to bend its curve, much earlier than the other countries. Contrary, Sierra Leone's educational expansion stagnated at a low level of 3-4 years of male education, and the gender gap persisted at 2 years post-independence. Tanzania followed a curve quite similar to countries in the first panel, achieving a comparatively fast expansion of male education, but with slightly smaller gender gaps throughout.

Botswana and South Africa, both had very small gender gaps compared to other SSA countries. In both cases, women in fact outperformed men for the most recent decades observed. The case of Lesotho is even more at odds with the overall pattern, with women accumulating more years of education than men during the entire period, reaching an absolute lead of almost 2 years by the 1970 birth cohort. Lesotho is the only country that does not follow the typical educational gender Kuznets curve at all. One possible explanation for the small gender gaps in Southern Africa is that women's marginalization from cattle farming had unintendedly benefitted their educational attainment, a factor that may also have been at play in Rwanda. In the case of Lesotho, sample selection bias may also play some role, as educated men may have disproportionally migrated to South Africa seeking employment, thus not being observed in the census contrary to (presumably less mobile) educated women and less educated men.

Late and high gender gap peak

Our third panel comprises four countries. Each of them witnessed major Christian missionary expansion, providing the bulk of formal education. Figure B.3(c) indicates that experiences within this group are heterogeneous. From very low levels at the start of the 20th century, Liberia saw its gender gap widen rapidly up to the 1950 birth cohort, before narrowing fast in subsequent decades. The widening of the gender gap in Benin and Nigeria was more gradual but also continued all the way up to the 1980s, suggesting a comparatively poor post-colonial performance in reducing gender inequality. The first cohorts observed in Malawi and Zimbabwe exhibited comparatively high levels of gender inequality but witnessed only modest increases subsequently. Malawi performed poorly in closing the gap after its peak in 1955, while Zimbabwe had closed most of its gap by 1985.

When we relate the absolute gap to male educational expansion in Figure B.4(c), we see that countries with late peaks initially followed a trajectory quite similar to countries with early and high peaks: growing gaps until approximately 4-6 years of male education. In the case of Nigeria and Zimbabwe, however, we observe that gender gaps persist at high levels as male education expanded to 9 and 10 years respectively. In other words, Nigeria and Zimbabwe failed to bend their educational gender Kuznets curves towards lower gender gaps despite sustained expansion of male education. Also striking is the fact that gender gaps in both Liberia and Zimbabwe had fallen substantially among cohorts in which male educational expansion had come to an abrupt halt, while female education continued to expand.

Late and low gender gap peak

This final panel contains four French colonies (Burkina Faso, Guinea, Mali, and Senegal), as well as Ethiopia, which remained independent for most of the colonial era. Figure B.3(d) displays that gender gaps were particularly low in Burkina Faso, Ethiopia and, Mali during the first half of the 20th century, but also did not decline much in the later decades. Gender gaps in Guinea and Senegal increased more sharply early on but experienced at least some reduction subsequently.

Placing the gender gaps in the context of male educational expansion, Figure B.4(d) reveals that low gender gaps were clearly linked to limited overall educational expansion, barely above 3 years of male education. This, in turn, is plausibly explained by the marginal role played by Christian missionaries in most of French colonial Africa, which already had different and firmly-rooted religious traditions at the start of the 20th century (Islam and, in the case of Ethiopia, Orthodox Christianity). Limited local demand for Christian conversion in those contexts thus resulted in a low supply of mission schools. In each of the countries in this cluster, we observe a similar initial expansion along the educational gender Kuznets curve as in the previous two country clusters. Perhaps surprisingly, Mali reduced the gap quite early on in its educational expansion trajectory. Senegal also bent its curve early (at about 3.5 years of male education), as male education barely expanded among those born in the birth cohorts 1950 to 1975.

B.4.3. Exploring factors related to sub-national gender gaps in sub-Saharan Africa

We now zoom in further to explore relevant regional characteristics within countries in a multivariate regression framework. Table B.4 reports the regression results for the gender gap in three time periods (1920-1939, 1940-1959, 1960-1979), controlling for spatial autocorrelation.[24] Our baseline results use country fixed-effects (columns 1-3) which capture country-specific unobservables. We also show results with regional fixed-effects (columns 4-6), which enable us to examine colonizer dummies and country-level fertility data. Our main results remain similar when we take the male-female ratio as the dependent variable (Appendix Table B.12). In the following, we discuss the regression results for each of the correlates introduced in the data and method section above: dynamic expansion of male education, openness, colonizer effects, religion, agriculture, and culture. Figure B.5 maps the educational gender gap at the sub-national level, after controlling for the linear and quadratic effects of male educational expansion, which is expected to have a strong, independent, inverse U-shaped effect on the gender gap. The Appendix provides variable definitions, source descriptions, and further base model specifications.[25]

*Male educational expansion***.** Previously, we have shown that on both world region and country levels the absolute gender gap tended to grow rapidly during early stages of male educational expansion, then flattened, and eventually fell, creating an inverted U-shaped relationship. By entering the linear and quadratic impact of male education in the gap regression in Table B.4, we capture this curvilinear relationship, which explains a large share of the variation we observe, and also allows for a cleaner interpretation of our other variables. We find that both linear and quadratic expansion in male education have a strong and statistically significant correlation with educational gender gaps throughout all periods (columns 1-3, 4-6),

[24] Gender gap and ratio results without spatial autocorrelation controls are shown in Appendix Tables B.9, B.11 and B.13 respectively. We have to drop 91 birth districts when controlling for spatial autocorrelation in the regression in order to establish repeated panels that are balanced and consistent.

[25] We specify our base model without controlling for spatial correlation (Appendix Tables B.9, B.11, and B.13).

consistent with an inversely U-shaped curve.[26]

Openness. We find some evidence that coastal regions had lower gender inequality over the colonial period (columns 1, 4 and 5). Our measure of urbanization, log city population (>10,000 inhabitants) per region, was consistently associated with less inequality (columns 1-3, 4-6) but is only significant in the early colonial period (columns 1, 4). Also, we find that the regional presence of colonial railroads was significantly and consistently associated with lower gender inequality across time (columns 1-3, 4-6). Overall, we find that better connected and urban locations tended to be linked to more gender equality, supporting the idea that increased openness benefited African girls' education during most of the 20th century.

Religion. Columns 1-6 show that regions in the initial European Christian missionary "heartlands" of the early 20th century had lower gender gaps even for cohorts born post-independence. Mission schools lost their monopoly in British Africa after the end of the colonial era (Frankema 2012), but these locational effects appear to have persisted and even grown in importance over time. When separating mission denominations, both the presence of Protestant and Catholic main stations is associated with lower educational gender inequality across time (see Appendix Table B.8).[27] Thus, contrary to earlier studies (Nunn 2014; Montgomery 2017), we do not find evidence for a differential effect of mission denominations on educational gender outcomes. Contrary, four out of the six columns indicate some evidence that Muslim majority regions had larger gender gaps over both early colonial and post-independence periods.

Agriculture. Contrary to Boserup's (1970) hypothesis, we do not find evidence that cash crop cultivation (or mining activities) affected gender gaps. We also do not find evidence that districts where women traditionally participated actively in agriculture had different educational gender gaps compared to districts where tasks in agriculture were mainly carried out by men (reference category). We interact the cash crop variable with the gender division of labor variables, to explore if cash crop adoption affected gender gaps differently depending on women's role in agriculture, yet this interaction does not yield significant results either. The variable expressing pasture relative to cropland indicates that greater suitability for pastoralism is positively correlated with gender gaps (but) only for the latest cohort (1960-1979).

[26] Beta coefficients for all variables are reported in Appendix Table B.10. The Beta coefficients of the male educational expansion variables are substantially larger than for the other variables.

[27] We thus do not find that Protestant missions had a larger (negative) effect on educational gender gaps than Catholics (Nunn 2014).

Family systems. We do not find evidence that low female autonomy aggravated educational gender inequality. Instead, we find some evidence for the post-colonial era (column 3) that low female autonomy is linked to lower gender gaps. Age at the onset of fertility is an obvious mechanism linking family systems to gender gaps in educational outcomes. We did not obtain historical district-level fertility data but included a country-level average fertility variable for the latest time period. We find that fertility increased gender gaps but did not change the signs or significance levels of the other variables.

Colonizer effects. To test for colonizer effects at the sub-national regional level, we introduce dummies for British colonies, mandated territories, and independent countries (columns 4-6), taking French colonies as reference category and using African region (rather than country) fixed effects. We confirm our tentative findings from SSA cross-country analysis that the regions' mandated and independent territories had significantly smaller gender gaps during colonial era cohorts than French dependencies (columns 4-5). We also find that regions in British colonies had smaller gaps for the 1940-1959 cohorts (column 5). Colonizer effects on gender gaps disappear after independence (column 6).

B.5. Discussion

We have conducted an exploration of gender inequality in education across developing regions, African countries, and country districts since the early colonial era. First, compared to other developing world regions, SSA started out the 20th century with small gender gaps but had the largest gaps by the 1980s. In all developing regions, we observe an inverse U-shaped relationship between the gender gap and male educational expansion, which we have termed *educational gender Kuznets curve*. Interestingly, along each stage of its curve, SSA had smaller gender gaps than other world regions. This finding should caution policy makers to attribute SSA's comparatively modest progress in closing the gender gap over the 20th century to male preference, and instead to acknowledge how SSA's gender inequality today is linked to its comparatively slow expansion of education. Potentially, then, one of the most effective policy interventions would be to stimulate overall educational expansion, especially in disadvantaged regions, which we should, based on the historical experience, expect to have strong benefits for girls in the medium- to long runs.

Second, our country comparison confirms this pattern of inverse U-shaped gender attainment gap trajectories. All 21 observed SSA countries, with the exception of Lesotho, saw an initial increase of their gender gaps until the mid-20th century. In most countries, gaps leveled off or declined subsequently. When we relate gender gaps to the trajectory of male educational expansion, we observe that most countries started out on very similar paths, with girls accumulating about 1 year of education for every 4 years accumulated by boys. Some countries did not yet progress beyond 4 years of male education for the latest observed birth cohort. Others had progressed much further. In some cases, such progress in male education was accompanied by a decisive bending of the educational gender Kuznets curve towards less inequality (Tanzania, Kenya); while in others, large gaps persisted (Malawi, Nigeria). The only major exceptions to this broader pattern are Botswana, Lesotho, South Africa, and Zimbabwe, all located in Southern Africa. While educational progress in South Africa and Zimbabwe had already advanced quite far at the start of the 20th century, this was much less the case for Lesotho and especially Botswana. Nevertheless, the latter two countries exhibit the smallest gender gaps. Potentially, male absence due to pastoralism and male labor migration has played a role in lowering their gender gaps, although our sub-national findings do not confirm an association between gender gaps and pastoralism (or any other of our agricultural variables).

As hypothesized on the basis of earlier literature on colonizer effects and religion, British colonies and countries with major Christian missionary presence during the colonial era experienced faster (male) educational expansion. They are also overrepresented among those countries with large gender gap peaks, suggesting that the supply and demand of mission schooling can be linked to rapidly rising gender differences in years of education. However, colonizer effects and religion are not clearly associated with gender gaps along the educational gender Kuznets curve at the country level. In most countries, whether Christian or Muslim or French or British colonies, gender gaps approximated 2 years at 3 years of male education. Cameroon, Rwanda, and Tanzania reduced their gender gaps comparatively early along the educational gender Kuznets curve, which suggests that League of Nations/United Nations mandated status may have played a role in achieving more gender-balanced education in a colonial context. However, many of the regularities observed during the colonial era break down in the post-colonial era, where we observe much heterogeneity, as some countries bent their Kuznets curve earlier (Rwanda, Senegal) or more decisively (Tanzania, Kenya, Zimbabwe) than others. This suggests that, despite clearly visible colonial legacies on education, gender gaps were strongly influenced by idiosyncratic policies and events in the post-colonial era, an issue that future studies can explore in more detail.

Third, we examined how various local factors were associated with sub-national inequality over time, keeping country- or region effects constant. Although our analysis does not establish causality, documenting relevant conditional correlations for such a large body of evidence on African gender equality in schooling brings us closer to identifying local factors that compound gender inequality on the continent. We observe that regional economies that benefited from urbanization, coastal access, or railway proximity also achieved more gender equality, compared to more remote places and regions characterized by agricultural labor markets and family economies. Globalization, long before the term had been invented, promoted gender equality in African education. Closer integration of marginalized regions in national, regional, and global economies may, therefore, plausibly contribute to reducing gender-unequal educational attainment. We do not find that cash crop agriculture was linked to gender gaps. Moreover, we do not find substantial evidence that the historical division of labor in agriculture and family systems were associated with gender gaps in education. This is reassuring, as it suggests that educational outcomes are not primarily driven by deeply rooted systems of gender inequality but rather by more dynamic and mutable forces, such as educational investment and economic change. Indeed, we find that districts with consolidated missionary presence in the early colonial era had lower gender inequality in years of schooling throughout the entire period studied. This illustrates how strong and lasting specific local investments in education can be, but also suggests that such investments had limited diffusive effects beyond specific locations.

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B.7. Tables and figures

B.7.1. Tables

Table B.1: Data sources, periods/units of observation and sample size

Geographical scope	Sources	Cohorts	Unit of obs.	Method	Obs.
1. Developing regions	Barro and Lee (2013)	1890-1979	Region	Time trend	4
2. Sub-Saharan Africa	36 Censuses (IPUMSI)	1885-1984	Country	Time trend	21
3. Sub-Saharan Africa	32 Censuses (IPUMSI)	1920-1979	District	Repeated cross section (regression)	1,177

Table B.2: Number of birth regions and observations per country and census year

Country	Census year	Birth decades used	N Regions	Obs.
Benin	1979	1920-1950	76	304
Benin	2013	1960-1970	77	154
Botswana	2001	1920-1950	19	74
Botswana	2011	1960-1970	19	38
Burkina Faso	1985	1920-1960	30	150
Cameroon	1976	1920-1950	112	447
Cameroon	2005	1960-1970	306	612
Ethiopia	1984	1920-1950	85	340
Ghana	1984	1920-1950	10	40
Ghana	2010	1960-1970	10	20
Guinea	1983	1920-1950	33	132
Guinea	1996	1960-1970	34	68
Kenya	1969	1920-1940	41	123
Kenya	2009	1960-1970	156	312
Lesotho	1996	1920-1950	1	4
Lesotho	2006	1960-1970	1	2
Liberia	1974	1920-1940	11	33
Liberia	2008	1960-1970	15	30
Malawi	1987	1920-1950	26	104
Malawi	2008	1960-1970	31	62
Mali	1998	1920-1950	45	180
Mali	2009	1960-1970	46	92
Rwanda	2002	1920-1970	101	606
Senegal	1988	1920-1950	30	120
Senegal	2002	1960-1970	34	68
Sierra Leone	2004	1920-1970	66	396
South Africa	2001	1920-1950	9	36
South Africa	2011	1960-1970	9	18
Tanzania	1988	1920-1950	25	100
Tanzania	2012	1960-1970	30	60
Uganda	1991	1920-1950	34	136
Uganda	2002	1960-1970	56	112
Zambia	1990	1920-1950	52	207
Zambia	2010	1960-1970	71	142
Total			1,701	5,322

Table B.3: Descriptive statistics, educational gender gap for all time periods

	1920-1939					1940-1959					1960-1979				
Variables	Obs.	Mean	SD	Min	Max	Obs.	Mean	SD	Min	Max	Obs.	Mean	SD	Min	Max
Educational gender gap	1,569	1.141	1.063	-3.600	6.500	1,529	1.833	1.164	-3.000	6.107	2,126	1.489	1.006	-2.100	5.394
Male years of education	1,569	1.598	1.560	0.000	11.000	1,529	3.352	2.243	0.051	10.000	2,126	5.592	2.753	0.1005	11.828
Male years of education sq.	1,569	4.987	10.204	0.000	121.000	1,529	16.261	18.705	0.003	100.000	2,126	38.850	30.485	0.010	139.892
Urban share (log)	1,569	0.125	0.646	0.000	5.252	1,529	0.231	0. 852	0.000	6.513	2,126	0.351	0.938	0.000	5.656
Dummy if railroad	1,569	0.253	0.435	0.000	1.000	1,529	0.250	0.433	0.000	1.000	2,126	0.239	0.427	0.000	1.000
Dummy if coast	1,569	0.099	0.299	0.000	1.000	1,529	0.095	0.293	0.000	1.000	2,126	0.086	0.280	0.000	1.000
Dummy if main mission 1924	1,569	0.251	0.434	0.000	1.000	1,529	0.241	0.428	0.000	1.000	2,126	0.227	0.419	0.000	1.000
Dummy if Protestant mission	1,569	0. 198	0.398	0.000	1.000	1,529	0.186	0.390	0.000	1.000	2,126	0.178	0 .382	0.000	1.000
Dummy if Catholic mission	1,569	0.117	0.322	0.000	1.000	1,529	0.116	0.321	0.000	1.000	2,126	0.096	0.295	0.000	1.000
Dummy if Muslim majority	1,569	0.296	0.46	0.000	1.000	1,529	0.302	0.459	0.000	1.000	2,126	0.244	0.429	0.000	1.000
Dummy if farm female	1,194	0.347	0.476	0.000	1.000	1,149	0.336	0.473	0.000	1.000	1,752	0.403	0.491	0.000	1.000
Dummy if farm shared	1,194	0.570	0.495	0.000	1.000	1,149	0.566	0.496	0.000	1.000	1,752	0.549	0.498	0.000	1.000
Cash crop p.c. (log)	1,529	0.563	1.158	0.000	5.945	1,500	0.664	1.231	0.000	6.594	2,106	1.310	2.183	0.000	9.295
Cash crop p.c. (log) * Dummy if farm female	1,154	0.276	0.825	0.000	4.977	1,120	0.336	1.034	0.000	6.594	1,732	0.665	1.799	0.000	9.295
Cash crop p.c. (log) * Dummy if farm shared	1,154	0.271	0.806	0.000	5.945	1,120	0.330	0.796	0.000	4.742	1,732	0.726	1.559	0.000	7.422
Minerals p.c. (log)	1,569	0.042	0.468	0.000	7.877	1,529	0.0311	0.401	0.000	7.299	2,126	0.003	0.039	0.000	0.995
Pasture / Cropland (log)	1,569	0.694	0.538	0.000	2.890	1,527	0.761	0.582	0.000	3.726	2,106	0.641	0.601	0.000	4.396
Low female autonomy index	1,335	0.037	1.653	-2.195	2.534	1,300	0.072	1.662	-2.195	2.534	1,666	0.204	1.584	-2.196	2.534
Fertility (log)	-	-	-	-	-	-	-	-	-	-	2,126	1.932	0.110	1.672	2.123
French colony	1,569	0.259	0.438	0.000	1.000	1,529	0.268	0.443	0.000	1.000	2,126	0.187	0.390	0.000	1.000
British colony	1,569	0.312	0.463	0.000	1.000	1,529	0.296	0.457	0.000	1.000	2,126	0.384	0.486	0.000	1.000
Mandated colony	1,569	0.297	0.457	0.000	1.000	1,529	0.307	0.461	0.000	1.000	2,126	0.406	0.491	0.000	1.000
Independent country	1,569	0.133	0.339	0.000	1.000	1,529	0.129	0.335	0.000	1.000	2,126	0.023	0.149	0.000	1.000

Table B.4: Correlates of sub-national educational gender gaps, panel regression

Dependent variable:	Educational gender gap			Educational gender gap		
	1920-1939	1940-1959	1960-1979	1920-1939	1940-1959	1960-1979
	(1)	(2)	(3)	(4)	(5)	(6)
Male years of education	1.053***	1.031***	0.565***	1.076***	0.948***	0.508***
	(0.054)	(0.033)	(0.036)	(0.060)	(0.032)	(0.033)
Male years of education sq.	-0.057***	-0.078***	-0.041***	-0.063***	-0.069***	-0.035***
	(0.013)	(0.004)	(0.003)	(0.014)	(0.004)	(0.003)
Urban share (log)	-0.077**	-0.009	-0.020	-0.139***	-0.012	-0.029
	(0.030)	(0.021)	(0.019)	(0.048)	(0.023)	(0.020)
Dummy if railroad	-0.069**	-0.191***	-0.168***	-0.067*	-0.229***	-0.205***
	(0.030)	(0.045)	(0.042)	(0.036)	(0.047)	(0.048)
Dummy if coast	-0.139**	-0.153	0.128	-0.134*	-0.167*	0.060
	(0.064)	(0.100)	(0.087)	(0.076)	(0.101)	(0.083)
Dummy if main mission 1924	-0.115***	-0.157***	-0.201***	-0.129***	-0.106*	-0.180***
	(0.039)	(0.054)	(0.049)	(0.047)	(0.060)	(0.052)
Dummy if Muslim majority	0.056**	-0.009	0.142**	0.051*	-0.028	0.185***
	(0.023)	(0.047)	(0.056)	(0.030)	(0.046)	(0.055)
Dummy if farm female	0.035	-0.085	-0.047	-0.060	-0.172***	0.023
	(0.041)	(0.058)	(0.051)	(0.050)	(0.062)	(0.056)
Dummy if farm shared	0.052	0.064	0.087*	0.025	0.018	0.095*
	(0.038)	(0.053)	(0.046)	(0.048)	(0.059)	(0.050)
Cash crop p.c. (log)	-0.006	-0.017	-0.004	0.062***	0.024	0.003
	(0.020)	(0.024)	(0.018)	(0.023)	(0.028)	(0.017)
Cash crop p.c. (log) * Farm female	-0.022	-0.023	-0.010	-0.006	-0.021	0.001
	(0.023)	(0.030)	(0.021)	(0.025)	(0.034)	(0.019)
Cash crop p.c. (log) * Farm shared	0.012	0.015	0.005	-0.044	0.039	0.019
	(0.024)	(0.028)	(0.021)	(0.027)	(0.033)	(0.020)
Minerals p.c. (log)	-0.083**	0.072	-0.366	-0.046	0.094	-0.101
	(0.039)	(0.077)	(0.251)	(0.047)	(0.079)	(0.246)
Pasture / Cropland (log)	0.040	-0.020	0.103***	0.028	0.016	0.121***
	(0.026)	(0.028)	(0.034)	(0.031)	(0.035)	(0.036)
Low female autonomy index	-0.002	-0.003	-0.023	-0.016	-0.028*	-0.027*
	(0.010)	(0.017)	(0.015)	(0.011)	(0.017)	(0.014)
British colony				-0.071	-0.327***	-0.107
				(0.060)	(0.071)	(0.075)
Mandated territory				-0.155**	-0.621***	0.048
				(0.079)	(0.143)	(0.111)
Independent country				-0.293***	-0.655***	0.276*
				(0.103)	(0.163)	(0.158)
Fertility rate						0.213***
						(0.058)
Constant	-0.029	-1.081***	-2.075***	0.228*	-2.099***	-5.750***
	(0.064)	(0.085)	(0.102)	(0.129)	(0.193)	(0.395)
Rho	-0.100	0.850***	1.432***			
	(0.089)	(0.049)	(0.002)			
Observations	1,554	1,462	2,082	1,554	1,462	2,082
No. admin. clusters	777	731	1,041	777	731	1,041
Country FE	Yes	Yes	Yes	No	No	No
Region FE	No	No	No	Yes	Yes	Yes
Decade FE	Yes	Yes	Yes	Yes	Yes	Yes

Note: Panel regressions for 3 periods with two decades respectively and a large number of regions in each panel. Models (1-3) include country fixed effects. Models (4-6) include African region fixed effects (Central Africa, East Africa, South Africa, West Africa) Regression models are corrected for spatial autocorrelation. Rho is the spatial autocorrelation coefficient. We include a control for population density (log). The reference category to the two farm variables is male dominated farming. Variables are temporally dynamic except those capturing initial and invariant condition: Dummy if main mission in year 1924; farming practices that were measured from Baumann (1928); Low female autonomy index constructed based on Murdock (1967); and coastal dummy. Robust standard errors (in parentheses) are clustered at the sub-national administrative level. Significance codes: *** p<0.01, ** p<0.05, * p<0.1. See Appendix for data construction and sources.

B.7.2. Figures

Figure B.1: Educational gender gaps in developing world regions, 1890-1980

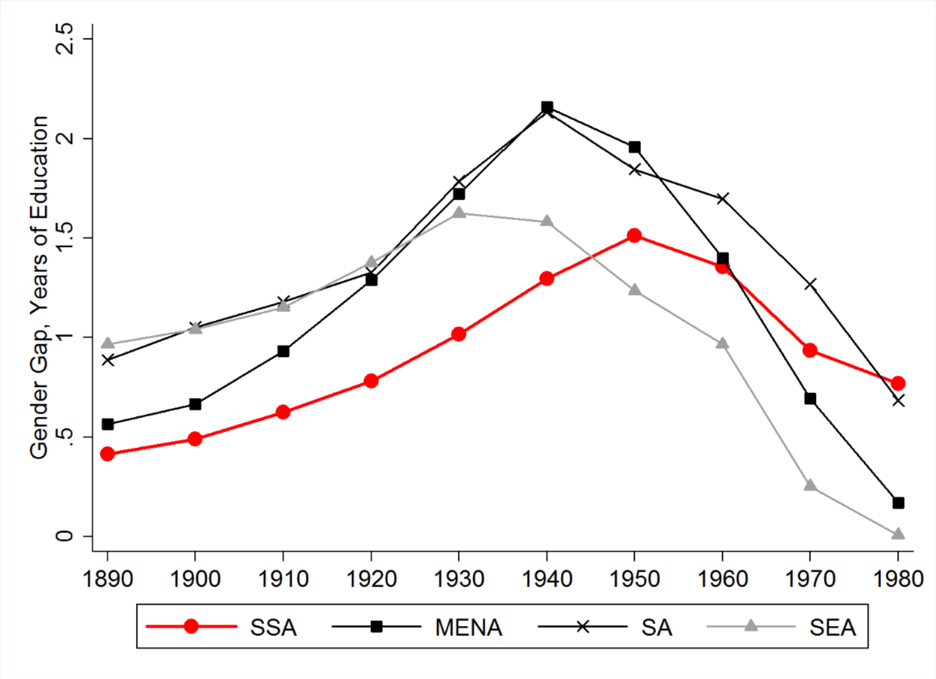
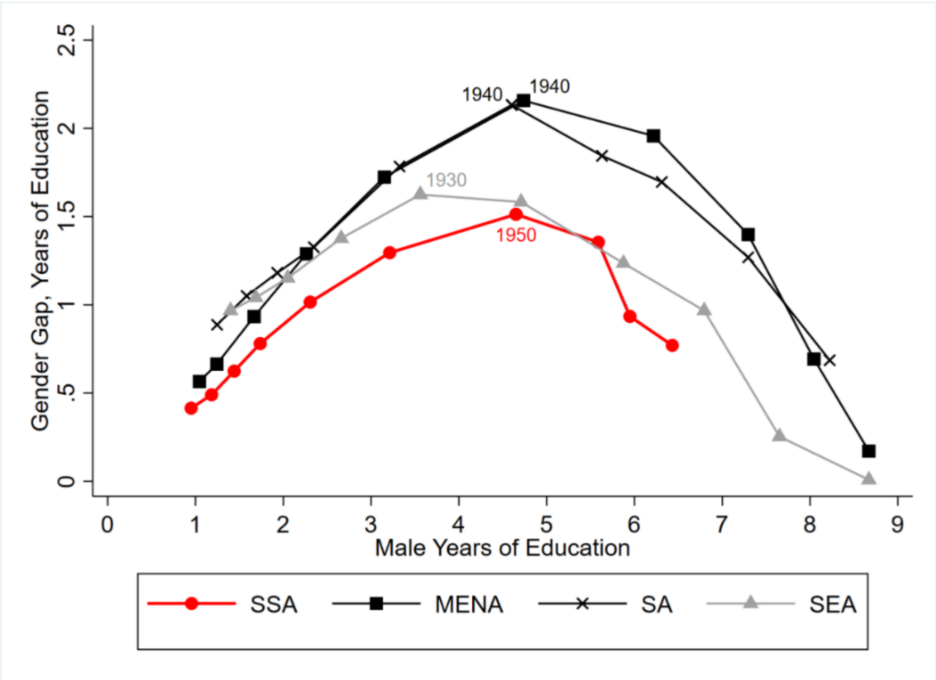


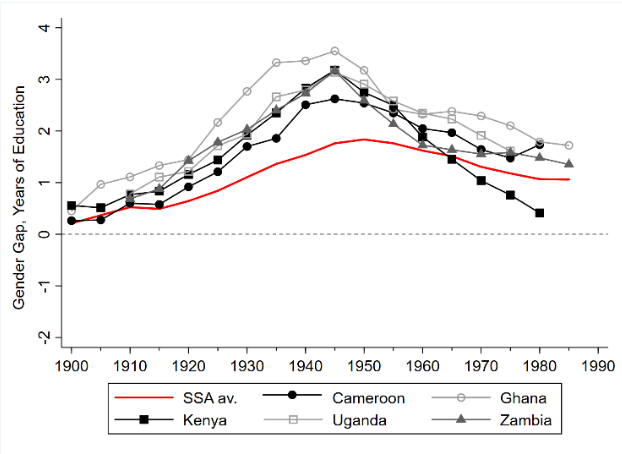
Figure B.2: Educational gender gaps and male years of education in developing world regions, 1890-1980



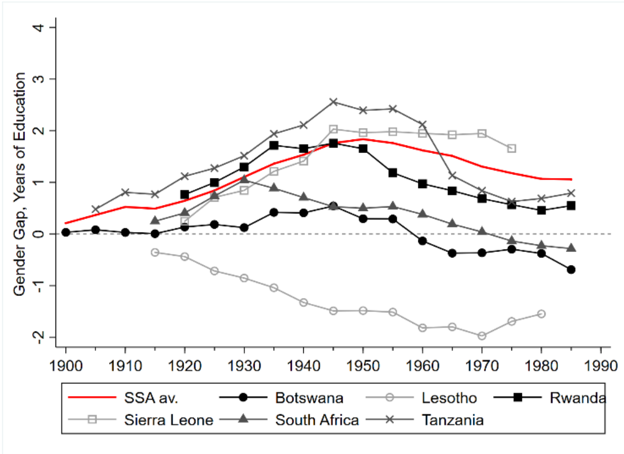
Note: Year figures in graph indicate the peak birth decade of the educational gender gap.

Figure B.3: Educational gender gaps in African countries, 1900-1985

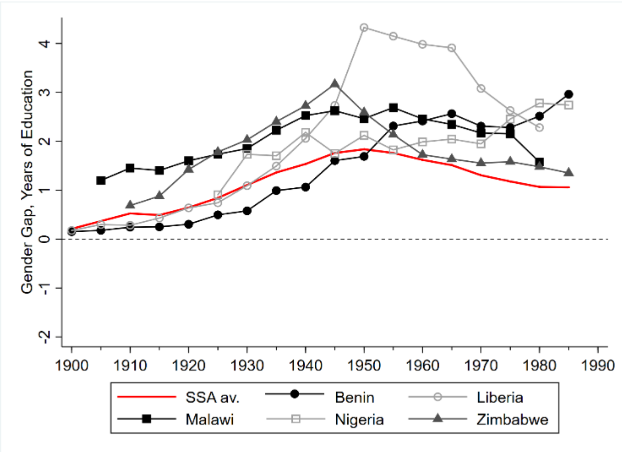
(a) Early high peak



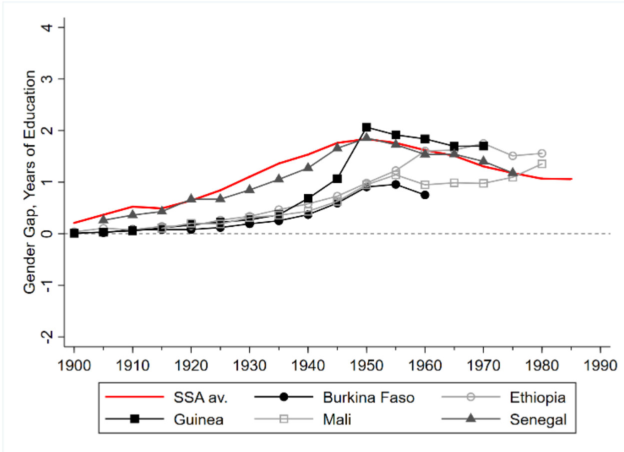
(b) Early low peak



(c) Late high peak

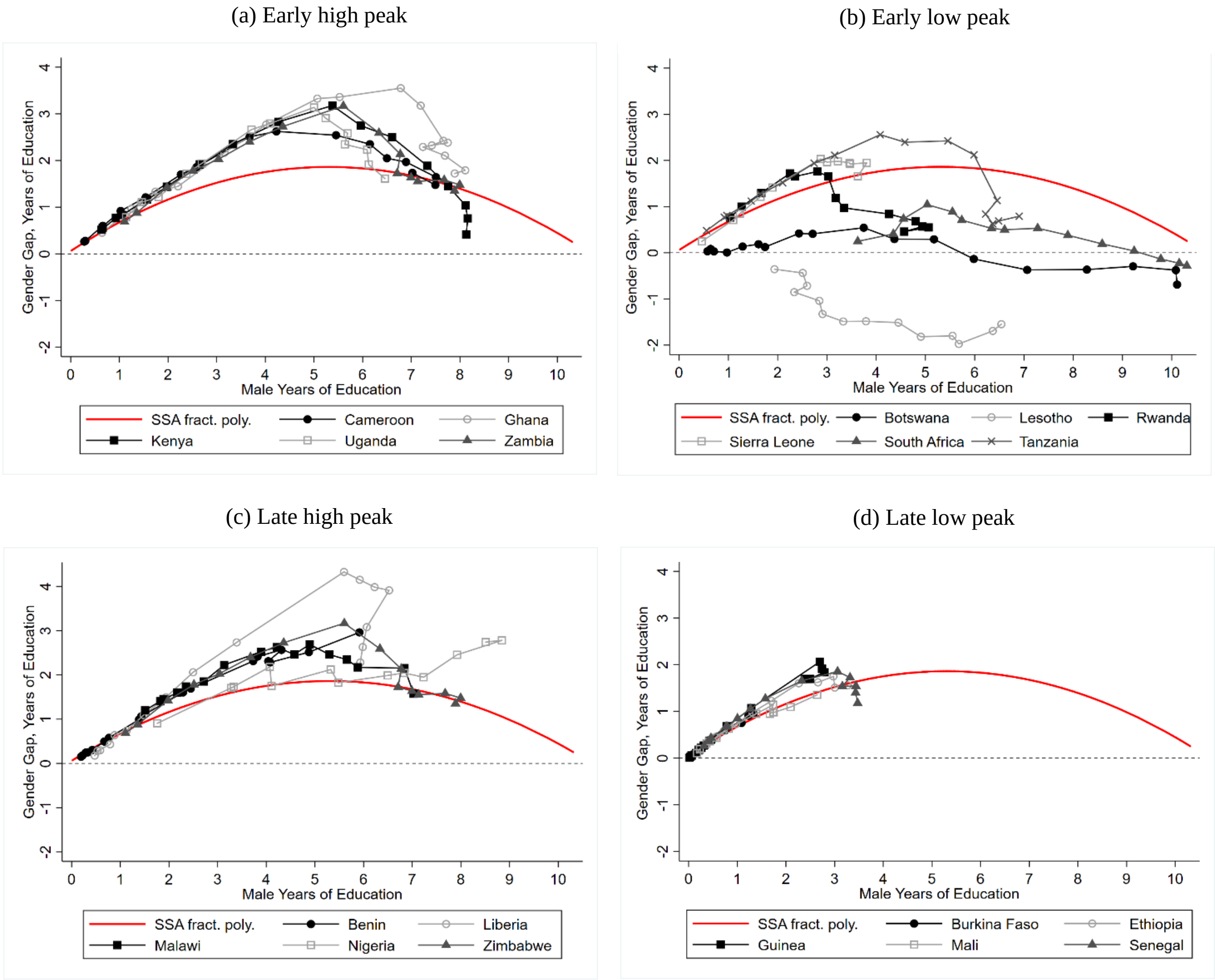


(d) Late low peak



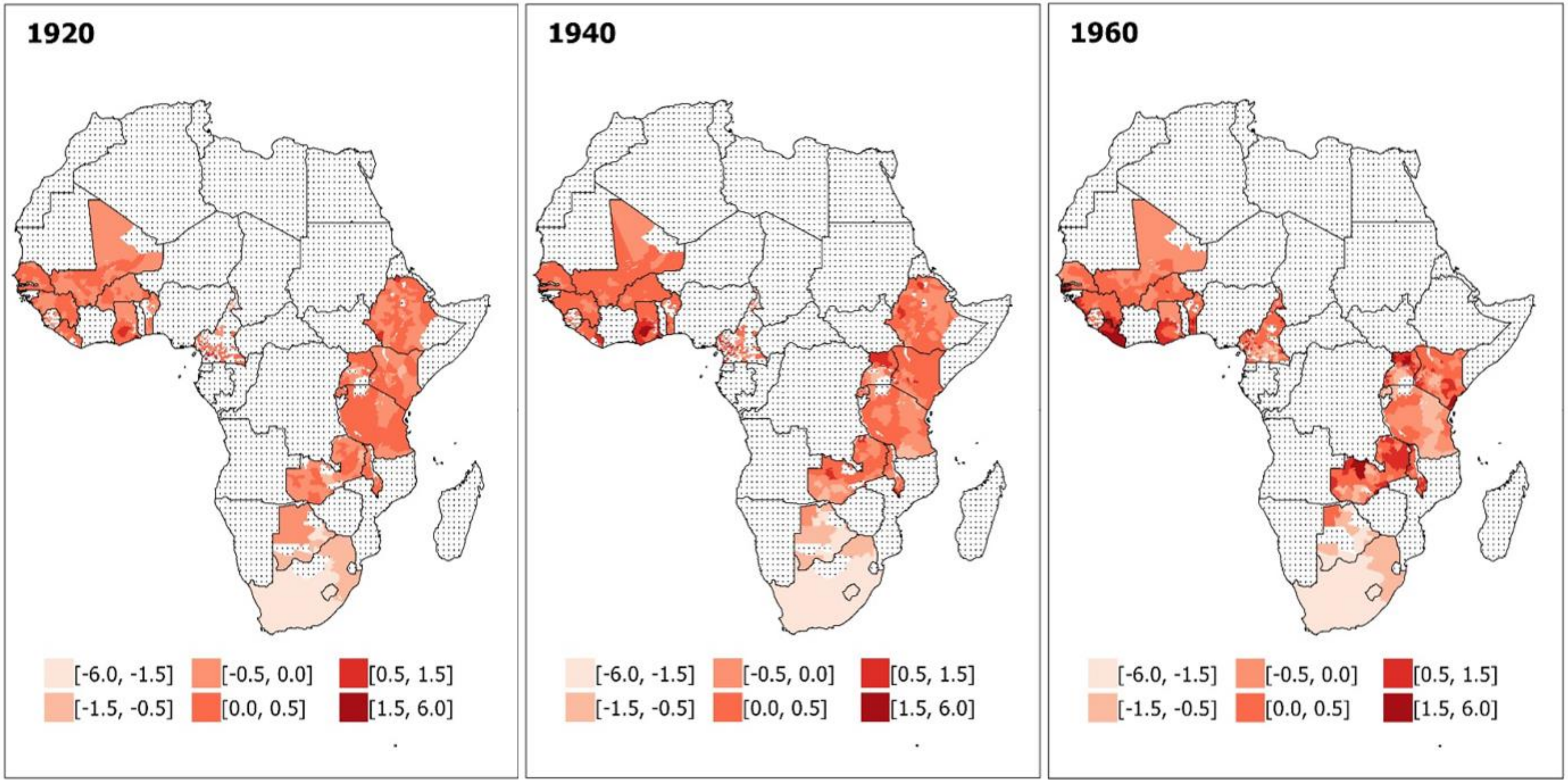
Note: Graphs show 5-year birth cohort averages. Gender gap of 0 indicates gender equality. Red line represents the average for our sub-Saharan African sample.

Figure B.4: Educational gender gaps and male years of education in African countries, 1900-1985



Note: Graphs show 5-year birth cohort averages. Gender gap of 0 indicates gender equality. Red line represents the fractional polynomial fit for our sub-Saharan African sample.

Figure B.5: Educational gender gaps per decade across sub-national sub-Saharan Africa



Note: Brighter color = smaller gender gaps. Educational gender gaps controlling for linear and quadratic effects of male years of schooling (educational gender Kuznets curve) for 1920s, 1940s and 1960s. No data available for 1960s Ethiopia.

B.8. Appendix

B.8.1. Data

Spatial units for sub-Saharan Africa

We assemble data for 1,177 sub-national units in 19 sub-Saharan African countries. While our final gap dataset contains 5,226 observations our final ratio dataset comprises 4,924 observations. Since in some regions women do not receive any education, the number of observations declines when we calculate the gender ratio which looks at the educational attainment of men relative to the one of women. For regions where the level of female schooling is zero, the ratio cannot be calculated (since the denominator would be zero), leading to a loss of observations. Table B.6 displays the number of observations per country and period, for the gap and the ratio dataset, respectively.

Gender inequality in educational attainment

For measuring the outcomes of educational gender inequality, we construct two dependent variables. First, we compute the gender gap, an absolute measure which expresses the educational difference between males, and females in years of schooling. Second, we calculate the male-female ratio in education, a relative measure which allows us to investigate educational outcomes for males relative to females. The dependent variables were constructed as follows:

Gender gap. Data for the years of schooling variable *(yrschool)* come from IPUMS-International, indicating the number of years of schooling for individuals, both males and females. We then calculate the average number of years of schooling per birth decade and birth region for men and women, respectively. Next, we reconstruct the absolute educational attainment gap between males and females by calculating the difference between male and female average years of schooling.

Gender ratio. For the construction of the gender ratio, we likewise use the *yrschool* variable from IPUMS and calculate the average number of years of schooling per birth decade and birth region for both genders. We then compute the educational gender inequality ratio by dividing the calculated average years of schooling for males by the average years of schooling for females. We take the natural logarithm of the educational gender ratio variable due to a highly skewed distribution of the sample. As already mentioned above we have to accept a decline in observations when using the educational gender ratio since the result of a division by zero in regions where women don't have any education is undefined.

Main control variables: determinants of educational gender inequality

Educational expansion

Male educational expansion. We obtain data on years of schooling for male individuals from IPUMS censuses and calculate the average number of years of schooling per birth region and decade. To account for the non-linear relationship that exists between the expansion of male education and the educational gender gap we include in addition to the male education variable its squared term in the gender gap regression. Since we do not observe this curvilinear relationship between the educational gender ratio and the male education variable we exclude the squared term from the ratio regression specifications.

Agriculture

Cash crop and mineral production. To estimate cash crop and mineral output per district for each decade, we combine various sources. First, we collect country-level export volumes for nine important cash crops (palm oil, palm kernels, groundnuts, cotton, cocoa, coffee, tea, tobacco, and cloves) and three minerals (copper, gold, and diamonds) from 1920 to 1959 from the African Commodity Trade Database (ACTD) (Frankema et al. 2018) and several other sources (Manning 1982; Mitchell 1995; Van Melkebeke 2017). Additionally, output data for agricultural commodities since 1960 are taken from the online database of the Food and Agriculture Organization (FAO). Mineral output in the period 1950-1979 is estimated based on 1957 output values from Hance et al. (1961), falling right into our period of interest. The included crops and minerals represent the most important exports from sub-Saharan Africa from c. 1920 to 1979, in terms of volume and value (Munro 1976). We exclude minor commodities, such as cashew nuts, copra, and maize. The included commodities were also almost entirely exported, with very limited domestic trade, which means that exports closely approximate total commercial output.

Second, we digitize a map by Hance et al. (1961) that contains the source regions of 95 percent of exports across 38 countries in sub-Saharan Africa in 1957, conveyed as points at the site of production, which each represent an equal unit of value. This map gives the most comprehensive and consistent overview of the spatial distribution of export production in colonial tropical Africa. It was first digitized and employed by Roessler et al. (2020) to study the long-run effects of Africa's cash crop revolution on spatial inequality today. The authors of that study confirmed the accuracy of the map, using data that they independently collected from colonial archives. The dataset covers twelve (groups of) agricultural products, as well as a wide range of minerals. Each of our crops and minerals of interest are included in the map individually, except for cloves, tea and tobacco which are, together with khat and chilies (which were not exported in sufficiently large quantities to enter our dataset) collated under "other stimulants and spices". The ACTD and FAO allow us to estimate the relative contribution of these different crops to each country's output of 'other stimulants and spices'.

Third, we intersect the Hance et al. (1961) map of African exports with our district borders to obtain a cross-sectional dataset containing the value of output per crop and mineral for each district in 1957. To obtain district-level time series from 1920 to 1979, we multiply country-level output for each year with the district-level value share in 1957 (district value / country value). This procedure is analogous but improves upon an approach used in various recent papers, which all have to deal with an absence of panel data on sub-national cash crop and mineral production (Jedwab and Moradi 2016; Papaioannou and de Haas 2017; Tadei 2020; Jedwab et al. 2022). The main difference is that these earlier papers use agro-climatic or agro-ecological crop suitability as an indirect predictor of sub-national cash crop output, while we use the actual 1957 spatial distribution of output.

As is the case with these other studies, our approach relies on the assumption that spatial patterns of crop- and mineral-specific output did not change much during our period of interest. This assumption is reasonable for several reasons. First, the source areas in 1957 are already extremely concentrated in a small number of districts (10 percent of the districts in our dataset produced 67.3 percent of all cash crops; 20 percent even produced 85.6 percent). It is telling that Hance et. Al. (1961) refer to producing areas as "islands". Such islands included the Senegambia estuary, the forest zone of Ghana, the shores of Lake Victoria, and several islands in East and West Africa, which were known as centers of cash crop production throughout our period of interest. Second, cash crop output is closely related to fixed or sticky geographical features, such as soil fertility and market access (roads, railroads, and rivers) which were largely determined by 1920. Indeed, studies on the distribution of cash crops in the interwar era show a very similar pattern and the same core areas, although output quantities are not directly comparable due to district border changes (Papaioannou and de Haas 2017; Miotto 2019). Third, in a land-abundant, labor-scarce, and infrastructurally underdeveloped context, colonial states had an interest to concentrate output in specific regions and stimulate labor migration to those regions to save costs (cf. Roessler et al. 2020), which lends further credibility to the existence of relatively fixed ‘islands’ of production. It should also be noted that even if some measurement error remains, our variable which captures actual production mid-20th century is more precise than indirect measures based solely on crop suitability.

Fourth, we sum up cash crop output and mineral value respectively for each district and each year and generate decadal averages for both variables. It should be noted that many districts did not export any of the nine crops and three minerals included in our dataset. Botswana and Zambia did not harbor any cash-crop exporting districts, hence we assign zeros. South Africa’s and Lesotho’s cash crop locations are not covered by Hance et al. (1961) and thus their 10 districts are dropped from the regression analysis.

Agricultural division of work by sex. We digitized the spatial distribution of five categories that indicate different degrees of men’s and women’s participation in agriculture (Figure B.9), as originally compiled by the German ethnographer Hermann Baumann (1928). Based on Baumann’s classification we construct the following three dummy variables to account for gender division in agriculture: (i) *farm male* (ref. category) takes the value 1 in areas where men traditionally do most of the agricultural work, 0 otherwise; (ii) *farm female* takes the value 1 in areas where farming is traditionally considered a female occupation, 0 otherwise; (iii) *farm shared* takes the value 1 if both sexes contribute substantially to agriculture.

Pastures relative to cropland. Several studies have used pastures (livestock) and cropland as indicators for female labor participation in agriculture (Alesina et al. 2013; Voigtländer and Voth 2013; Baten et al. 2017). We calculate the log of the relative share of pastureland to cropland in squared kilometers. For doing so we use Klein Goldewijk et al.’s (2017) estimates of pastureland and cropland from the History Database of the Global Environment (Hyde). Since this variable is widely distributed, we drop observations within that variable based on percentiles and keep a percentile range from 1 to 99. Due to dropping these outliers our observations contained in the final dataset decline from 5,318 to 5,226.

Population pressure. We calculate the population number per district based on IPUMS data and divide it by the area of birth regions based on our own GIS calculations.

Openness

Urbanization. As a proxy for urbanization, we consider the share of the urban population per birth region. To construct this variable, we aggregate the population of cities with more than 10,000 inhabitants (Africapolis, OECD 2020) per birth region and divide it by the total district population. We divide the total city population by 10 before calculating the urban share which allows us to normalize it to the IPUMS census (10 percent) data district birth population. We then construct this variable for the decades 1920, 1950, and 1970, respectively.

Colonial railroads. Railroads are drawn from the GIS database used in Jedwab and Moradi (2016). We create a time-variant binary variable that takes the value 1 if the railroad line was present during a certain decade within a birth region, 0 otherwise.

Coast. The coastal dummy variable takes the value 1 if the district has a coastline, 0 otherwise.

Religion

Christian missions. Data for the presence of Christian missions come from Nunn (2010) based on a digitized map in Roome (1925). We create a dummy equal to 1 if a Christian mission (Protestant or Catholic) is located in a district and equal to 0 if there is none. We also study the individual effect of Protestant and Catholic mission denominations and thus create three dummy variables. One dummy takes the value 1 if Protestant missions, 0 otherwise. Another dummy takes the value 1 if Catholic missions, 0 otherwise and the third dummy variable is used as a reference category and equals 1 if there are no missions, 0 otherwise. Note, that the Christian mission variable only shows European residence stations by 1924 that were more likely to have larger churches, congregations, and a school and were more likely to be located in economically developed, connected, and densely populated areas (Jedwab, Meier zu Selhausen and Moradi 2022). We attempt to control for the endogenous placement of these early missions by controlling for districts' urban population share, railroad presence, cash crop and mineral exports, coastal access, and Muslim majority.

Muslim majority. We obtain the religion variable from IPUMS. It comprises major religious groups including no religion, Buddhist, Hindu, Jewish, Muslim and Christian. Since we have already included a Christian Mission variable in our analysis and want to avoid multicollinearity among our predictors, we do not create an additional Christian variable using IPUMS data but compute the share of Muslims in the population. We then create a binary variable that takes the value 1 if Muslims constitute more than 50 percent of the population in an administrative subdivision, 0 otherwise.

Cultural practices of low female autonomy

Low female autonomy. We create an index of three variables that proxy cultural practices regarding low female autonomy. We obtain information about the practice of brideprice, patrilineality, and polygamy within the various Murdock regions from the Murdock Ethnographic Atlas (1967). To see in which parts of our birth regions these cultural customs are practiced we intersect the borders of the birth regions with the Murdock regions and construct three new variables that indicate the share of birth regions in which the practice of bride price, patrilineality, and polygamy prevail, respectively (omitting areas with no Murdock observations from the shares). To construct the low female autonomy variable we first invert the bride price variable (i.e. *1- brideprice*) and create a *no_brideprice* variable since the practice of bride price is associated with the wellbeing of women (Ashraf et al. 2020) and not with low female autonomy. We then create the low female autonomy variable, a linear combination of the *no_brideprice, polygamy,* and *patrilineality* variables, by performing a Principal Component Analysis (PCA).

Political economy

Colonizer identity. We create a dummy for colonizer's identity for territories being ruled by the British (Ghana, Guinea, Malawi, Nigeria, Sierra Leon, Uganda, Zambia), the French (Benin, Burkina Faso, Mali, Senegal, Western Cameroon), League of Nations mandate (Cameroon, Rwanda, Tanzania), or independent during (most of) the period considered (Ethiopia, Liberia, South Africa). French Colonizer is used as reference category.

Fertility rate

Data on the total fertility rate (births per woman) 1960-1979 come from the World Bank (2021).

B.8.2. Spatial autocorrelation test

Because spatial methods require a weighting matrix to link each observation of the dependent variable to every contemporaneous observation from a different geographical unit's dependent and independent variables, they require strongly balanced panels. Unfortunately, as with most studies in social science, we do not have a perfectly balanced panel and must resort to an alternative strategy. This is a common problem in the spatial econometrics literature, with researchers either having to drop all panels with any missing data whatsoever or having to revert to imputation. For sources on multiple imputation in spatial econometrics, see Griffith et al. (1989); Stein (1999); LeSage and Pace (2004); Griffith and Paelinck (2011); Baker et al. (2014); Bihrmann and Ersbøll (2015).

To perform our imputation, we used Stata's mi command with its multivariate regression option, using this statistical simulation technique to effectively create 50 new datasets of predicted values for each panel. The following analysis is then performed on each simulated dataset separately before the results are pooled using Rubin's Rules (Rubin 1987). According to Rubin (1987), these estimates afford valid inferences despite the increased sample size of the underlying analysis, provided that data are missing at random. Our spatial analysis utilizes a simple spatial econometric model, the Spatial Autoregressive Model (SAR Model; equation 1).

$$Y_{it} = \rho W Y_{it} + \beta_1 X1_{it} + \beta_2 X2_i + \beta_3 X3_{it} + \mu_c + \upsilon_t + \varepsilon_{it} \quad (1)$$

where Y_{it} represents respectively the educational gender gap and educational gender ratio in region *i* and time period *t;* $X1_{it}$ is a matrix of all time-varying regressors in region *i* and time period *t*; $X2_i$ is a matrix of all time-invariant regressors in region *i*; $X3_{it}$ is a matrix of our interaction variables; μ_c and υ_t respectively represent country and time (decadal) fixed effects; ε_{it} is a vector of spatially lagged errors; W is an inverse distance weighting matrix constructed using the coordinates of geographic birth region centroids. ρ is the spatial autocorrelation coefficient.

The SAR Model controls for the direct effect that variation in the dependent variable of other birth regions may have on birth region i (measured by ρ) i.e., the effect of educational gender inequality spillovers from neighbors. While more complex models can be estimated, these often suffer from multicollinearity, or else fail to converge (Burkey 2017).[28] Additionally, our estimate of ρ from each of these simpler specifications indicate that spatial correlation is influential in our analysis.

[28] For example: The Spatial Durbin Model (SDM; LeSage and Pace 2009) simultaneously captures spillover effects from neighboring dependent and independent variables, the Kelejian-Prucha Model (Kelejian and Prucha 1998) considers spillovers from the dependent variable and error term, while all three spatial terms are included in the Manski Model (Manski 1993).

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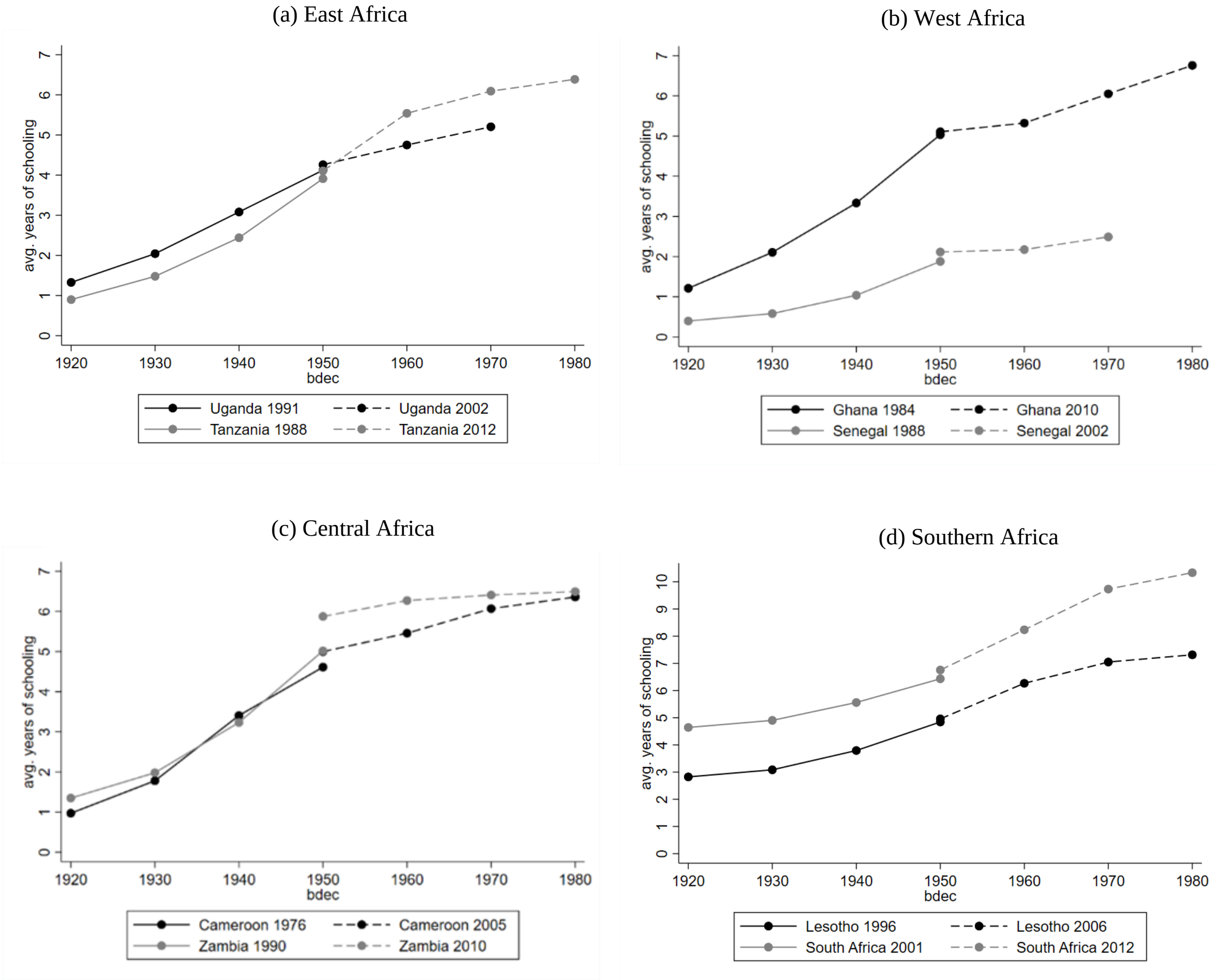
B.8.4. Survivor bias analysis

Figure B.6: Survivor Bias, cohort analysis for different regions in Africa



B.8.5. Figures and maps

Figure B.7: Educational male-female ratios and male years of education in developing world regions, 1890-1980

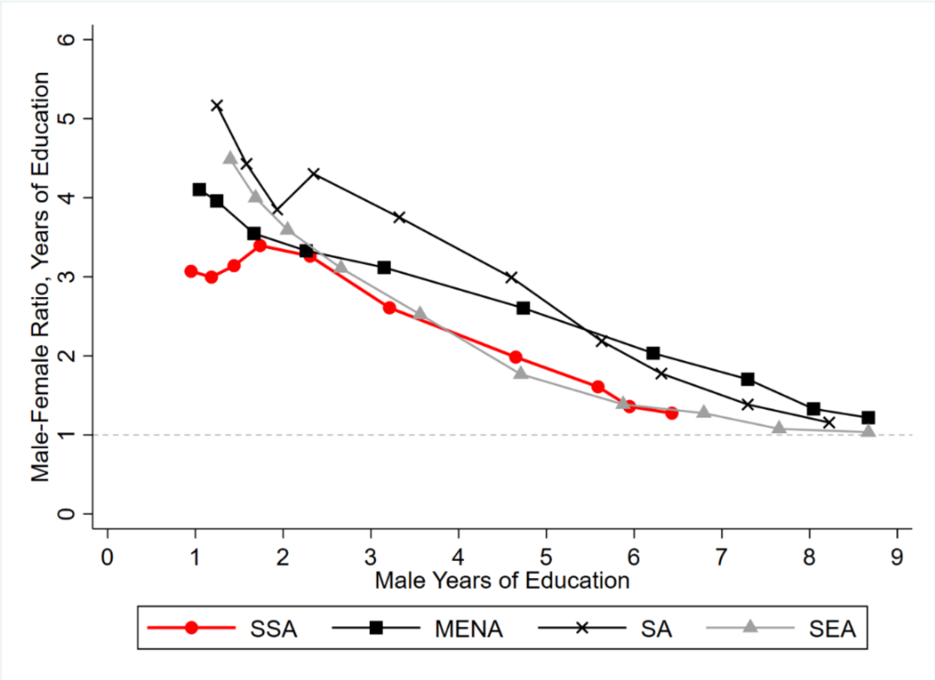
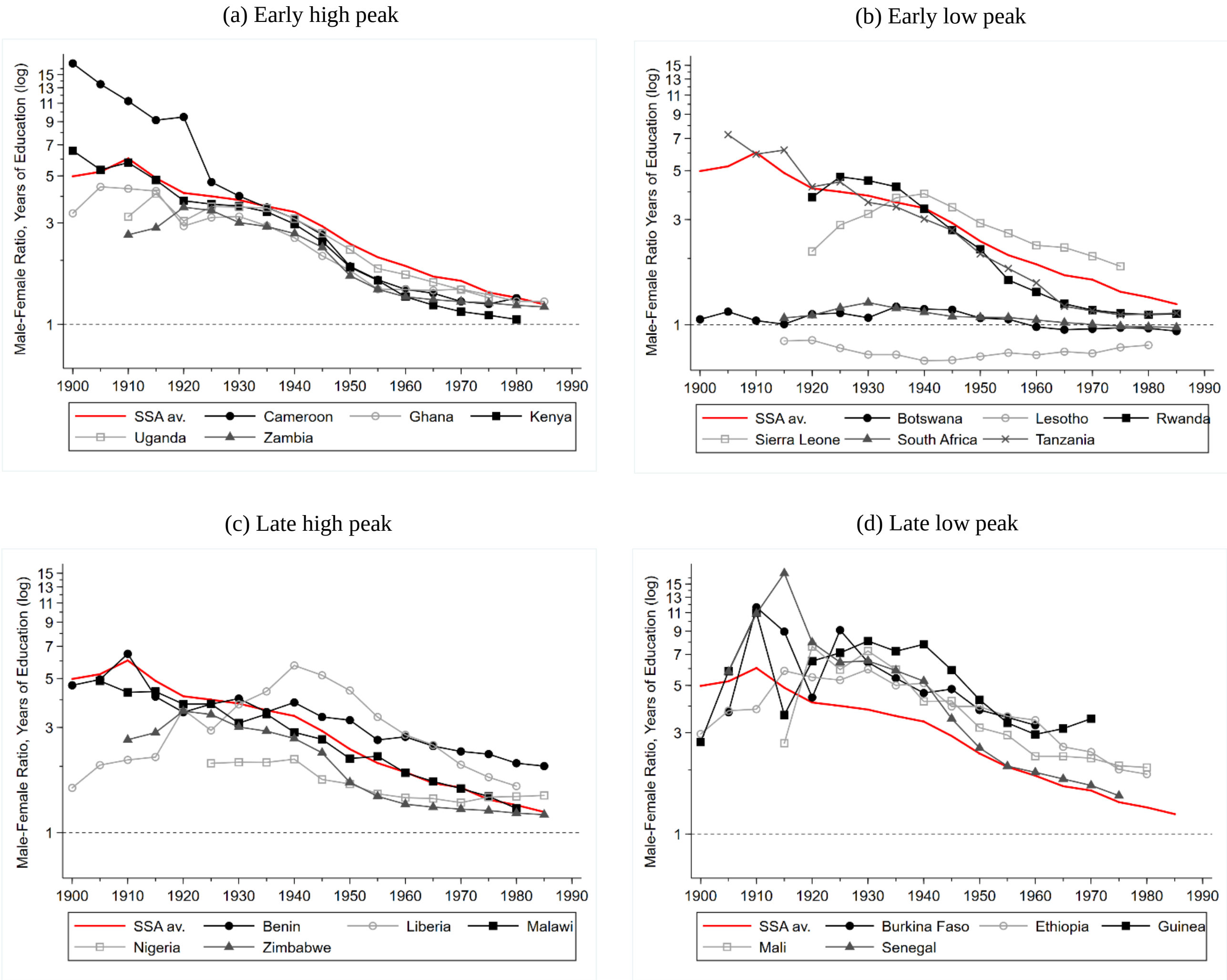


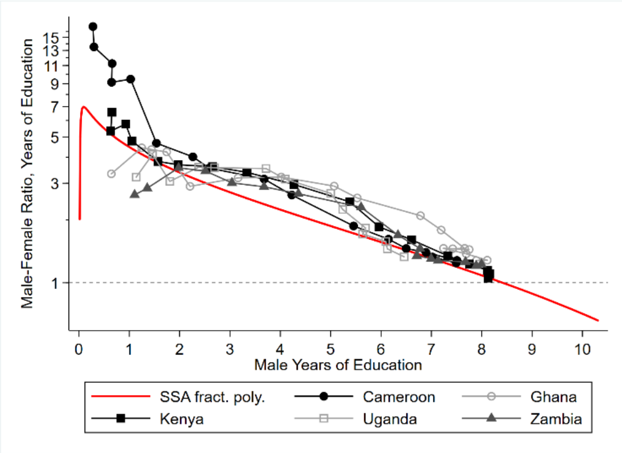
Figure B.8: Educational male-female ratio in African countries, 1900-1985



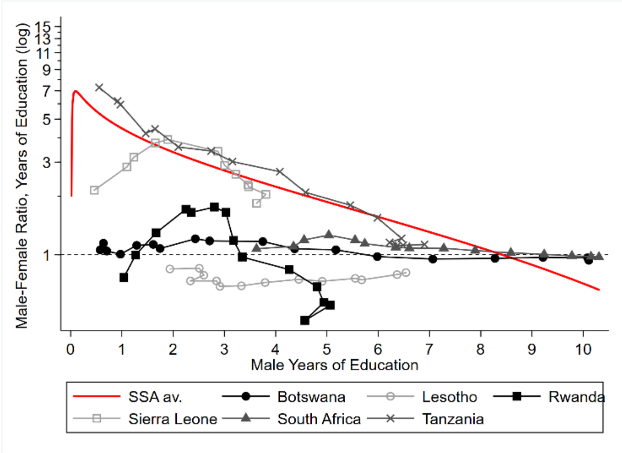
Note: Graphs show 5-year birth cohort averages. Male-female ratio of 1 indicates gender equality. Red line represents the average for our sub-Saharan African sample.

Figure B.9: Educational male-female ratios and male years of education in African countries, 1900-1985

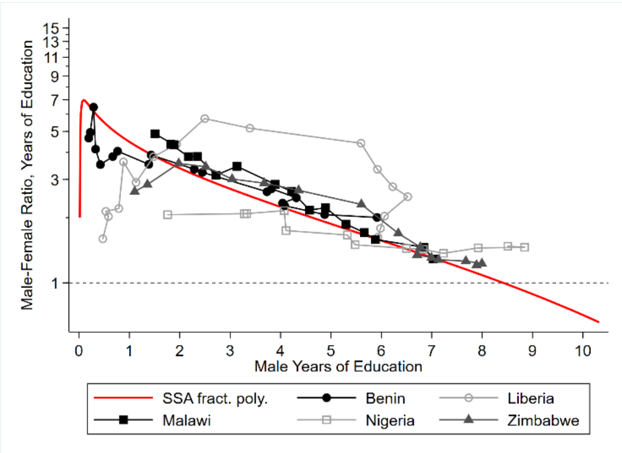
(a) Early high peak



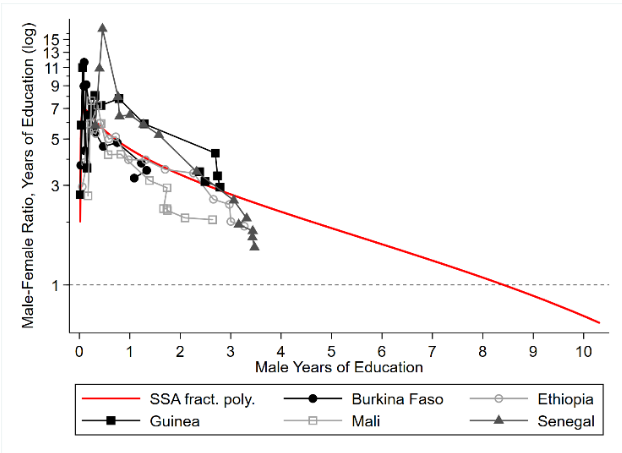
(b) Early low peak



(c) Late high peak

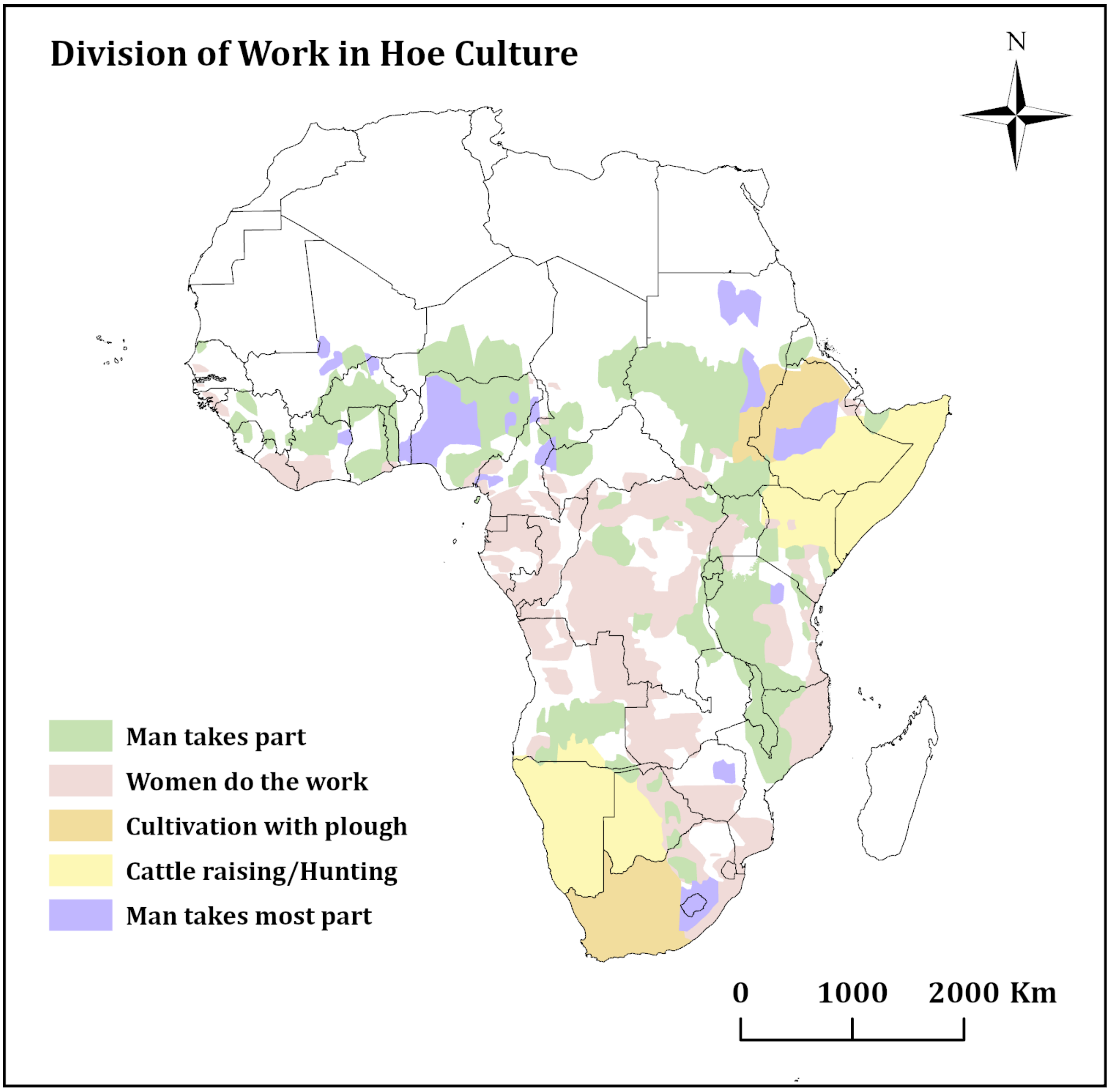


(d) Late low peak



Note: Graphs show 5-year birth cohort averages. Male-female ratio of 1 indicates gender equality. Red line represents the fractional polynomial fit for our sub-Saharan African sample.

Figure B.10: Division of work in hoe culture in sub-Saharan Africa



Source: Digitized from Baumann (1928, p. 303).

Note: The linked variable names in the regression tables are as follows: *farm shared* (man takes part), *farm female* (women do the work) and *farm male* (man takes most part, cultivation with plough, and cattle raising/hunting).

B.8.6. Sample construction and descriptive statistics

Table B.5: Sample construction

Country	Census year	Fraction of pop., %	N_{all}	$N_{age\ 25\text{-}80,\ educ}$	$N_{age\ 25\text{-}80, educ}$ Male, %	$N_{age\ 25\text{-}80, educ,}$ Female, %	$N_{birth\ regions}$
Benin	1979	10	321,639	110,888	45	55	76
Benin	2013	10	973,181	319,358	46	54	77
Botswana	2001	10	160,837	61,276	46	54	19
Botswana	2011	10	192,303	80,472	46	54	19
Burkina Faso	1985	10	838,963	255,337	43	57	30
Cameroon	1976	10	530,720	192,928	46	54	112
Cameroon	2005	10	1,480,837	477,895	47	53	306
Ethiopia	1984	10	360,885	233,991	43	57	85
Ghana	1984	10	1,057,940	327,666	44	56	10
Ghana	2010	10	2,433,834	955,288	46	54	10
Guinea	1983	10	453,093	181,186	47	53	33
Guinea	1996	10	692,175	250,607	47	53	34
Kenya	1969	6	600,040	208,333	59	41	41
Kenya	2009	10	3,759,026	1,304,266	49	51	156
Lesotho	1996	10	187,795	72,124	47	53	1
Lesotho	2006	10	180,208	74,209	47	53	1
Liberia	1974	10	144,337	56,474	50	50	11
Liberia	2008	10	338,809	121,658	49	51	15
Malawi	1987	10	746,526	253,846	48	52	26
Malawi	2008	10	1,320,183	429,732	49	51	31
Mali	1998	10	973,938	310,729	46	54	45
Mali	2009	10	1,107,648	350,139	48	52	46
Nigeria	2006-10	0.6	426,395	166,202	49	51	-
Rwanda	2002	10	746,978	238,424	45	55	101
Senegal	1988	10	676,313	217,609	47	53	30
Senegal	2002	10	972,925	340,945	48	52	34
Sierra Leone	2004	10	362,402	131,737	46	54	66
South Africa	2001	10	3,643,062	1,653,673	45	55	9
South Africa	2011	8.6	4,102,679	1,919,113	45	55	9
Tanzania	1988	10	2,271,445	771,871	48	52	25
Tanzania	2012	10	4,481,851	1,597,048	47	53	30
Uganda	1991	10	1,505,350	473,690	48	52	34
Uganda	2002	10	2,457,456	764,287	51	49	56
Zambia	1990	10	665,468	230,340	47	53	52
Zambia	2010	10	1,234,750	411,452	49	51	71
Zimbabwe	2012	5	654,688	244,417	47	53	-
Total			43,056,679	15,789,210			1,701

Table B.6: N districts by country and time period in gender gap and ratio datasets

	Gender gap			Gender ratio		
Country	1920-1939	1940-1959	1960-1979	1920-1939	1940-1959	1960-1979
Burkina Faso	60	60	30	46	59	30
Benin	130	134	140	70	121	140
Botswana	34	36	38	34	36	38
Cameroon	218	219	602	181	217	602
Ethiopia	170	170	-	160	170	-
Ghana	20	20	20	20	20	20
Guinea	66	66	68	30	65	68
Kenya	82	41	312	76	38	312
Liberia	22	11	30	21	11	30
Lesotho	2	2	2	2	2	2
Mali	90	90	92	57	89	92
Malawi	52	52	62	52	52	62
Rwanda	198	200	202	167	199	202
Sierra Leone	132	132	132	92	129	132
Senegal	60	60	68	53	60	68
Tanzania	50	50	60	50	50	60
Uganda	66	66	110	66	66	110
South Africa	16	16	18	16	16	18
Zambia	101	104	142	99	104	142
Total	1,569	1,529	2,128	1,292	1,504	2,128

Table B.7: Descriptive statistics, educational gender ratio (M/F)

	1920-1939					1940-1959					1960-1979				
Variables	Obs.	Mean	SD	Min	Max	Obs.	Mean	SD	Min	Max	Obs.	Mean	SD	Min	Max
Gender educational ratio (M/F)	1,292	1.760	0.922	-0.969	6.634	1,504	1.200	0.696	-1.424	4.354	2,126	0.541	0.504	-0.492	3.266
Urban share (log)	1,292	0.152	0.709	0.000	5.252	1,504	0.234	0.859	0.000	6.513	2,126	0.351	0.938	0.000	5.656
Dummy if railroad	1,292	.278	0.448	0.000	1.000	1,504	0.254	0.435	0.000	1.000	2,126	0.240	0.427	0.000	1.000
Dummy coast	1,292	0.114	0.318	0.000	1.000	1,504	0.096	0.295	0.000	1.000	2,126	0.086	0.280	0.000	1.000
Dummy if main mission 1924	1,292	0.295	0.456	0.000	1.000	1,504	0.244	0.430	0.000	1.000	2,126	0.227	0.419	0.000	1.000
Dummy if Protestant mission	1,292	0.231	0.421	0.000	1.000	1,504	0.189	0.392	0.000	1.000	2,126	0.178	0.382	0.000	1.000
Dummy if Catholic mission	1,292	0.141	0.348	0.000	1.000	1,504	0.118	0.323	0.000	1.000	2,126	0.096	0.295	0.000	1.000
Dummy if Muslim majority	1,292	0.298	0.457	0.000	1.000	1,504	0.297	0.457	0.000	1.000	2,126	0.243	0.429	0.000	1.000
Male years of education	1,292	1.847	1.576	0.011	11.000	1,504	3.394	2.233	0.073	10.000	2,126	5.592	2.753	0.101	11.828
Dummy if farm female	1,034	0.370	0 .483	0.000	1.000	1,141	0.336	0.472	0.000	1.000	1,752	0..403	0.491	0.000	1.000
Dummy if farm shared	1,034	0.554	0.497	0.000	1.000	1,141	0.567	0.496	0.000	1.000	1,752	0.549	0.498	0.000	1.000
Cash crop p.c. (log) * Dummy if farm female	995	0 .309	0 .860	0.000	4.773	1,112	0.339	1.037	0.000	6.594	1,732	0.665	1.799	0.000	9.295
Cash crop p.c. (log) * Dummy if farm shared	995	0.291	0.789	0.000	4.736	1,112	0.332	0.798	0.000	4.742	1,732	0.726	1.559	0.000	7.422
Cash crop p.c. (log)	1,253	0.605	1.142	0.000	5.627	1,475	0.672	1.235	0.000	6.594	2,106	1.310	2.183	0.000	9.295
Minerals p.c. (log)	1,292	0.0480	0.505	0.000	7.877	1,504	0.0316	0.404	0.000	7.299	2,126	0.003	0.039	0.000	0.995
Pasture / Cropland (log)	1,292	0.700	0.524	0.000	2.890	1,502	0.765	0.581	0.000	3.726	2,124	0.717	0.565	0.000	3.726
Low female autonomy index	1,111	-0.047	1.651	-2.195	2.534	1,288	0.068	1.663	-2.195	2.534	1,666	0.204	1.584	-2.195	2.534
Fertility rate (log)	-	-	-	-	-	-	-	-	-	-	2,126	1.932	0.110	1.672	2.123
French colony	1,292	0.198	0.399	0.000	1.000	1,504	0.262	0.440	0.000	1.000	2,126	0.187	0.390	0.000	1.000
British colony	1,292	0.341	0 .474	0.000	1.000	1,504	0.297	0.457	0.000	1.000	2,126	0.383	0.486	0.000	1.000
Mandated colony	1,292	0.308	0.462	0.000	1.000	1,504	0.310	0.463	0.000	1.000	2,126	0.406	0.491	0.000	1.000
Independent colony	1,292	0.152	.360	0.000	1.000	1,504	0.130	0.337	0.000	1.000	2,126	0.023	0.149	0.000	1.000

B.8.7. Additional regressions and robustness tests

Table B.8: Correlates of the educational gender gap, panel mission denominations and controlling for spatial autocorrelation

Dependent variable:	Educational gender gap		
	1920-1939	1940-1959	1960-1979
	(1)	(2)	(3)
Male years of education	1.053***	1.030***	0.563***
	(0.054)	(0.033)	(0.036)
Male years of education sq.	-0.057***	-0.078***	-0.041***
	(0.013)	(0.004)	(0.003)
Urban share (log)	-0.074**	-0.011	-0.020
	(0.030)	(0.021)	(0.019)
Dummy if railroad	-0.067**	-0.187***	-0.165***
	(0.030)	(0.045)	(0.042)
Dummy if coast	-0.144**	-0.163*	0.125
	(0.062)	(0.099)	(0.087)
Dummy if Catholic mission 1924	-0.148**	-0.085	-0.147**
	(0.058)	(0.059)	(0.065)
Dummy if Protestant mission 1924	-0.036	-0.118*	-0.153***
	(0.044)	(0.061)	(0.052)
Dummy if Muslim majority	0.050**	-0.007	0.143**
	(0.023)	(0.047)	(0.056)
Dummy if farm female	0.034	-0.077	-0.045
	(0.038)	(0.054)	(0.049)
Dummy if farm shared	0.050	0.066	0.088*
	(0.041)	(0.056)	(0.050)
Cash crop p.c. (log)	-0.006	-0.012	-0.003
	(0.019)	(0.024)	(0.018)
Cash crop p.c. (log) * Farm female	-0.023	-0.030	-0.012
	(0.021)	(0.030)	(0.021)
Cash crop p.c. (log) * Farm shared	0.011	0.010	0.004
	(0.024)	(0.028)	(0.022)
Minerals p.c. (log)	-0.080**	0.071	-0.383
	(0.040)	(0.077)	(0.235)
Pasture / Cropland (log)	0.043	-0.020	0.104***
	(0.026)	(0.028)	(0.034)
Low female autonomy index	-0.001	-0.005	-0.024
	(0.010)	(0.016)	(0.016)
Constant	-0.0227	-1.088***	-2.063***
	(0.065)	(0.0871)	(0.102)
Rho	-0.106	0.852***	1.432***
	(0.089)	(0.0487)	(0.002)
Observations	1,554	1,462	2,082
No. Admin. Clusters	777	731	1,041
Country FE	Yes	Yes	Yes
Decade FE	Yes	Yes	Yes

Note: Panel regressions for 3 periods, two decades respectively. Regression models are corrected for spatial autocorrelation. Rho indicates the spatial autocorrelation coefficient. We omit the coefficient of population density (log). Variables are temporally dynamic except those capturing initial and invariant conditions: dummy if coast; dummy if main mission in year 1924; the 2 farming variables measured by Baumann (1928) (reference category: male dominated farming); low female autonomy index constructed from Murdock (1967). Robust standard errors (in parentheses) are clustered at the sub-national administrative level. Significance codes: *** p<0.01, ** p<0.05, * p<0.1. See Web-Appendix for data construction and sources.

Table B.9: Correlates of the educational gender gap, panel without controlling for spatial autocorrelation

Dependent variable:	Educational gender gap			Educational gender gap			Educational gender gap		
	1920-1939			1940-1959			1960-1979		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Coef	Beta	S.E.	Coef	Beta	S.E.	Coef	Beta	S.E.
Urban share (log)	-0.001	-0.0004	(0.0297)	-0.043	-0.029	(0.048)	-0.004	-0.004	(0.030)
Dummy if railroad	-0.032	-0.015	(0.036)	-0.119*	-0.056	(0.065)	-0.096	-0.052	(0.070)
Dummy if coast	-0.004	-0.001	(0.060)	0.079	0.025	(0.113)	0.368***	0.131	(0.111)
Dummy if main mission 1924	-0.130***	-0.063	(0.037)	-0.291***	-0.140	(0.084)	-0.282***	-0.151	(0.098)
Dummy if Muslim majority	0.001	0.0004	(0.0352)	-0.013	-0.005	(0.068)	-0.092	-0.035	(0.102)
Male years of education	0.964***	1.341	(0.052)	1.163***	2.420	(0.064)	0.800***	2.005	(0.084)
Male years of education sq.	-0.057***	-0.396	(0.012)	-0.087***	-1.537	(0.008)	-0.063***	-1.842	(0.007)
Cash crop p.c. (log)	-0.060**	-0.064	(0.024)	-0.084*	-0.085	(0.049)	-0.041	-0.094	(0.035)
Dummy if farm female	0.032	0.015	(0.057)	-0.097	-0.045	(0.135)	-0.053	-0.028	(0.122)
Dummy if farm shared	0.119**	0.048	(0.049)	0.232*	0.091	(0.126)	0.092	0.041	(0.121)
Cash crop p.c. (log) * Farm female	-0.016	-0.014	(0.044)	-0.039	-0.032	(0.082)	-0.022	-0.043	(0.044)
Cash crop p.c. (log) * Farm shared	0.103***	0.100	(0.027)	0.089	0.081	(0.061)	0.057	0.123	(0.036)
Minerals p.c. (log)	0.194***	0.088	(0.054)	0.348***	0.121	(0.084)	7.461	0.052	(5.968)
Pasture / Cropland (log)	0.017	0.008	(0.027)	-0.030	-0.014	(0.054)	0.079	0.039	(0.071)
Low female autonomy index	-0.010	-0.012	(0.012)	-0.010	-0.012	(0.025)	-0.074**	-0.114	(0.033)
Constant	-0.148**		(0.057)	-0.574***		(0.151)	-0.578***		(0.177)
Observations	1,016			985			1,404		
R-squared	0.960			0.871			0.639		
Country FE	Yes			Yes			Yes		
Decade FE	Yes			Yes			Yes		
No. Admin. Clusters	183			186			197		

Note: Panel regressions for 3 periods, two decades respectively including country FEs. Regression models are not corrected for spatial autocorrelation. We omit the coefficient of population density (log). Regressions are weighted by district population to account for different sizes of birth regions. Variables are temporally dynamic except those capturing initial and invariant condition: dummy if coast; dummy if main mission in year 1924; the 2 farming variables measured by Baumann (1928) (reference category: male dominated farming); low female autonomy index constructed from Murdock (1967). Observations are clustered at the level of ethnic regions from the Murdock (1967). Significance codes: *** p<0.01, ** p<0.05, * p<0

Table B.10: Standardized (Beta) coefficients from Table 4

Dependent variable:	Educational gender gap		
	1920-1939	1940-1959	1960-1979
	(1)	(2)	(3)
Urban share (log)	-0.0499	-0.007	-0.019
Dummy if railroad	-0.030	-0.081	-0.071
Dummy if coast	-0.040	-0.042	0.035
Dummy if main mission 1924	-0.049	-0.065	-0.084
Dummy if Muslim majority	0.025	-0.004	0.060
Male years of education	1.537	2.283	1.536
Male years of education sq..	-0.486	0.025	-1.238
Cash crop p.c. (log)	-0.007	-0.021	-0.009
Dummy if farm female	0.017	-0.040	-0.023
Dummy if farm shared	0.026	0.032	0.043
Cash crop p.c. (log) * Farm female	-0.018	-0.024	-0.019
Cash crop p.c. (log) * Farm shared	0.010	0.011	0.007
Minerals p.c. (log)	-0.037	0.029	-0.015
Pasture / Cropland (log)	0.022	-0.012	0.058
Low female autonomy index	-0.003	-0.005	-0.036
Observations	1,554	1,462	2,082
Country FE	Yes	Yes	Yes
Decade FE	Yes	Yes	Yes
No. Admin. Clusters	777	731	1,041

Table B.11: Correlates of the educational gender gap, panel without controlling for spatial autocorrelation with region FE

Dependent variable:	Educational gender gap			Educational gender gap			Educational gender gap		
	1920-1939			1940-1959			1960-1979		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Coef	Beta	S.E.	Coef	Beta	S.E.	Coef	Beta	S.E.
Urban share (log)	0.003	0.002	(0.028)	-0.037	-0.025	(0.035)	-0.013	-0.014	(0.024)
Dummy if railroad	-0.025	-0.012	(0.029)	-0.096*	-0.045	(0.054)	-0.089	-0.048	(0.059)
Dummy if coast	0.015	0.005	(0.055)	0.064	0.020	(0.089)	0.354***	0.126	(0.108)
Dummy if main mission 1924	-0.119***	-0.057	(0.029)	-0.201***	-0.097	(0.058)	-0.278***	-0.149	(0.069)
Dummy if Muslim majority	0.021	0.009	(0.029)	0.040	0.017	(0.056)	-0.237***	-0.089	(0.088)
Male years of education	0.970***	1.350	(0.044)	1.191***	2.478	(0.051)	0.937***	2.348	(0.056)
Male years of education sq.	-0.060***	-0.410	(0.010)	-0.090***	-1.600	(0.006)	-0.078***	-2.270	(0.005)
Cash crop p.c. (log)	-0.010	-0.011	(0.027)	-0.017	-0.017	(0.041)	-0.044	-0.099	(0.029)
Dummy if farm female	0.031	0.015	(0.040)	-0.074	-0.034	(0.088)	-0.074	-0.039	(0.090)
Dummy if farm shared	0.123***	0.049	(0.037)	0.287***	0.112	(0.080)	0.050	0.022	(0.085)
Cash crop p.c. (log) * Farm female	-0.016	-0.014	(0.030)	-0.055	-0.046	(0.046)	-0.010	-0.020	(0.032)
Cash crop p.c. (log) * Farm shared	0.066**	0.064	(0.029)	0.051	0.047	(0.049)	0.058*	0.125	(0.030)
Minerals p.c. (log)	0.191***	0.086	(0.060)	0.335***	0.117	(0.077)	6.636	0.047	(5.461)
Pasture / Cropland (log)	0.020	0.009	(0.021)	-0.001	-0.0004	(0.0458)	0.017	0.008	(0.053)
Low female autonomy index	-0.018*	-0.021	(0.010)	-0.055***	-0.067	(0.017)	-0.070***	-0.107	(0.021)
British colonies	-0.017	-0.008	(0.051)	-0.116	-0.055	(0.106)	-0.130	-0.069	(0.145)
Mandated territories	-0.014	-0.006	(0.058)	-0.460***	-0.202	(0.108)	-1.090***	-0.539	(0.173)
Independent countries	0.097	0.024	(0.076)	0.187	0.046	(0.151)	0.446***	0.069	(0.151)
Fertility rate (log)							-2.008***	-0.164	(0.459)
Constant	0.068		(0.076)	0.104		(0.154)	3.985***		(0.856)
Observations	1,016			985			1,404		
R-squared	0.957			0.860			0.610		
Region FE	Yes			Yes			Yes		
Decade FE	Yes			Yes			Yes		
No. Admin clusters	183			186			197		

Note: Panel regressions for 3 periods, two decades respectively including region FEs. Regression models are not corrected for spatial autocorrelation. We omit the coefficient of population density (log). Regressions are weighted by district population to account for different sizes of birth regions. Variables are temporally dynamic except those capturing initial and invariant condition: dummy if coast; dummy if main mission in year 1924; the 2 farming variables measured by Baumann (1928) (reference category: male dominated farming); low female autonomy index constructed from Murdock (1967). Observations are clustered at the level of ethnic regions from Murdock (1967). Significance codes: *** p<0.01, ** p<0.05, * p<0.1.

Table B.12: Correlates of the educational gender ratio (M/F), panel controlling for spatial autocorrelation

Dependent variable:	Educational male/female ratio (log)		
	1920-1939	1940-1959	1960-1979
	(1)	(2)	(3)
Male years of education	-0.136***	-0.096***	-0.054***
	(0.036)	(0.016)	(0.005)
Urban share (log)	-0.034	-0.030**	-0.031***
	(0.033)	(0.014)	(0.008)
Dummy if railroad	-0.180***	-0.102***	-0.077***
	(0.057)	(0.032)	(0.016)
Dummy if coast	-0.125	-0.092	-0.055
	(0.108)	(0.073)	(0.035)
Dummy if main mission 1924	-0.222***	-0.150***	-0.080***
	(0.076)	(0.041)	(0.015)
Dummy if Muslim majority	0.008	-0.009	0.024
	(0.099)	(0.061)	(0.037)
Dummy if farm female	0.022	-0.032	0.004
	(0.098)	(0.061)	(0.026)
Dummy if farm shared	0.118	0.037	0.025
	(0.106)	(0.064)	(0.025)
Cash crop p.c. (log)	0.052	-0.002	0.005
	(0.042)	(0.028)	(0.007)
Cash crop p.c. (log) * Farm female	-0.063	-0.024	-0.008
	(0.052)	(0.031)	(0.008)
Cash Crop p.c. (log) * Farm shared	-0.037	-0.015	-0.004
	(0.052)	(0.032)	(0.008)
Minerals p.c. (log)	-0.004	0.005	0.054
	(0.042)	(0.028)	(0.101)
Pasture / Cropland (log)	-0.097	-0.012	0.041**
	(0.065)	(0.031)	(0.016)
Low female autonomy index	-0.001	-0.007	-0.001
	(0.023)	(0.013)	(0.006)
Constant	1.234***	-0.316***	0.108**
	(0.324)	(0.117)	(0.054)
Rho	0.436***	1.336***	1.403***
	(0.119)	(0.016)	(0.015)
Observations	1,124	1,418	2,082
No. Admin. Clusters	562	709	1,041
Country FE	Yes	Yes	Yes
Decade FE	Yes	Yes	Yes

Note: Panel regressions for 3 periods, two decades respectively. Regression models are corrected for spatial autocorrelation. Rho indicates the spatial autocorrelation coefficient. We omit the coefficient of population density (log). Variables are temporally dynamic except those capturing initial and invariant conditions: dummy if coast; dummy if main mission in year 1924; the 2 farming variables measured by Baumann (1928) (reference category: male dominated farming); low female autonomy index constructed from Murdock (1967). Robust standard errors (in parentheses) are clustered at the sub-national administrative level. Significance codes: *** p<0.01, ** p<0.05, * p<0.1. See Web-Appendix for data construction and sources.

Table B.13: Correlates of the educational gender ratio (M/F), panel without controlling for spatial autocorrelation

Dependent variable:	Educational male/female ratio (log)			Educational male/female ratio (log)			Educational male/female ratio (log)		
	1920-1939			1940-1959			1960-1979		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Coef	Beta	S.E.	Coef	Beta	S.E.	Coef	Beta	S.E.
Urban share (log)	0.130**	0.116	(0.057)	-0.043**	-0.054	(0.020)	-0.033***	-0.082	(0.008)
Dummy if railroad	-0.106*	-0.073	(0.060)	-0.086***	-0.074	(0.031)	-0.041***	-0.052	(0.015)
Dummy if coast	0.125	0.056	(0.110)	0.094	0.053	(0.058)	0.062**	0.053	(0.031)
Dummy if main mission 1924	-0.382***	-0.262	(0.078)	-0.163***	-0.143	(0.033)	-0.065***	-0.084	(0.017)
Dummy if Muslim majority	0.020	0.011	(0.120)	-0.039	-0.030	(0.055)	0.008	0.007	(0.041)
Male years of education	-0.240***	-0.469	(0.029)	-0.144***	-0.544	(0.013)	-0.092***	-0.556	(0.006)
Cash crop p.c. (log)	0.0003	0.0005	(0.054)	-0.034	-0.063	(0.030)	-0.006	-0.032	(0.008)
Dummy if farm female	-0.026	-0.018	(0.107)	-0.122**	-0.102	(0.048)	-0.011	-0.014	(0.025)
Dummy if farm shared	0.275**	0.156	(0.117)	0.143**	0.102	(0.067)	0.069***	0.075	(0.027)
Cash crop p.c. (log) * Farm female	0.027	0.035	(0.049)	0.019	0.030	(0.028)	-0.005	-0.023	(0.008)
Cash crop p.c. (log) * Farm shared	0.098*	0.138	(0.052)	0.009	0.016	(0.031)	0.008	0.041	(0.008)
Minerals p.c. (log)	0.292***	0.194	(0.062)	0.108***	0.069	(0.026)	2.404*	0.041	(1.326)
Pasture / Cropland (log)	-0.047	-0.029	(0.074)	-0.047	-0.039	(0.035)	0.040**	0.048	(0.018)
Low female autonomy index	0.021	0.036	(0.034)	-0.007	-0.015	(0.015)	-0.014**	-0.051	(0.007)
Population density (not shown)	0.005	0.008	(0.028)	0.006	0.011	(0.016)	0.006	0.020	(0.007)
Constant	1.901***		(0.204)	1.918***		(0.101)	1.256***		(0.107)
Observations	875			981			1,404		
R-squared	0.392			0.701			0.766		
Country FE	Yes			Yes			Yes		
Decade FE	Yes			Yes			Yes		
No. Clusters	176			186			197		

Note: Panel regressions for 3 periods, two decades respectively. Regression models are not corrected for spatial autocorrelation. We omit the coefficient of population density (log). Variables are temporally dynamic except those capturing initial and invariant conditions: dummy if main mission in year 1924; the 2 farming variables measured by Baumann (1928) (reference category: male dominated farming); low female autonomy index constructed from Murdock (1967); and coastal share. Robust standard errors (in parentheses) are clustered at the sub-national administrative level. Significance codes: *** p<0.01, ** p<0.05, * p<0.1. See Web-Appendix for data construction and sources.

C. Educated Girls, a Force for Development?

Gender Inequality in Education and Economic Performance in Sub-Saharan Africa: A Path-Dependency Analysis

Abstract

The importance of human capital formation for economic growth has been widely researched and discussed, however, little attention has been paid to the relationship between gender disparities in education and economic performance. In this persistence study, we analyze the long-term effects of prevailing gender gaps in education during the 20th century on current per capita output in sub-Saharan Africa. Would this region have drawn economic benefits from an equally shared provision of education between men and women during the past century? Based on 19 sub-Saharan African countries, 1,107 administrative regions, and a total of 5,322 observations, results of our repeated cross-sectional study show a strong negative association between the existence of educational gender gaps during the past century and current nighttime light intensity per capita, our proxy for regional economic development, indicating that path dependency caused by these gender disparities, plays a role. Going beyond the analysis of direct effects, we find that part of this negative correlation between gender inequality in schooling and economic development is mediated through fertility. Although we do not make causal claims, our findings reveal that sub-Saharan Africa would likely have realized economic gains in terms of higher per capita output from increased investment in female education. Controlling for other potential drivers of economic growth, we find that inter alia educational expansion, coastal location, access to railroads, the endowment of minerals, labor migration, the initial stage of a region's economic development, and to some extent, democracy and life expectancy at birth matter for better economic performance[29].

[29] This chapter is single-authored.

C.1. Introduction

Human capital is widely considered one of the fundamental factors promoting economic welfare since it is the groundwork on which sustainable economic development and social wellbeing are built. It is generally acknowledged that education contributes to poverty reduction and fosters technical progress and development. Therefore, human capital plays a key role when analyzing economic growth across different parts of the world. Although there is a vast literature available that investigates the relationship between human capital and economic performance, only a small number of studies have explicitly focused on the correlation between the gender gap in education and economic growth (e.g., Barro and Lee 1994; Klasen 2002; Klasen et al. 2009). Gender-based disparities exist in all aspects of society and have become a central characteristic of development, not only on intrinsic grounds but also because of societal and economic benefits. Working towards achieving gender equity is crucial, especially in human capital, since gender gaps in education may have a negative influence on gender imbalances in a wide range of socio-economic realms, starting with domestic inequity but also affecting the employment sector and public life in general.

Since the mid-20th century, countries in most parts of the world have made significant progress towards closing the gender gap in education, yet no country in sub-Saharan Africa (SSA) has achieved gender parity in primary and secondary education (UNESCO 2015). According to Baten et al. (2021), absolute gender inequality in education rose steadily, although heterogeneously, in most countries during the early stages of educational expansion in sub-Saharan Africa. This process took place in the first half of the 20th century with gender inequality peaking at different levels between 1945 and 1960. Thereafter, with male educational expansion, African countries witnessed a decline in the educational gender gap, albeit at different paces. Baten et al. (2021) refer to this phenomenon as the *educational gender Kuznets curve*, since the evolution of gender inequality in education followed an inverse U-shaped trajectory. However, despite sub-Saharan African countries experiencing a shift towards more educational gender equity in the second half of the 20th century, in comparison with other world regions including the Middle East and North Africa (MENA), South Asia, and Southeast Asia, SSA depicted the highest levels of educational gender inequality by the 1980s, persisting until today (Barro and Lee 2015). Figure C.1 shows the development of the gender gap in education in the different world regions during the 20th century.

In the existing literature, there is no clear consensus to what extent gender inequality in education hampers economic performance or to what extent promoting women's education contributes to sustainable economic benefits. Some older empirical contributions report a puzzling result, indicating that male education has positive externalities on economic growth whereas female schooling negatively affects economic output (Barro and Lee 1994; Barro and Sala-i-Martin 1995). These studies use educational attainment (primary, secondary, etc.) indicators and include simultaneously male and female schooling as separate regressors to measure gender effects of education on economic growth. Based on a sample of 116 countries Barro and Lee (1994) run two cross-country regressions for the periods 1965-1975 and 1975-1985 and justify their results by stating that a large gap between female and male educational attainment may be a good measure of "backwardness". Therefore, a low level of female educational attainment indicates lack of progress, providing room for potential growth through the convergence mechanism. These findings have attracted much discussion. Stokey (1994) replicates the study of Barro and Lee (1994) and concludes that female education turns out to be insignificant when controlling for regional fixed effects. Besides she draws attention to the existing multicollinearity problem between the male and female education factors. Lorgelly and Owen (1999), also replicate Barro and Lee's estimates and detect influential observations on four East Asian countries (Hong Kong, Korea, Singapore, and Taiwan) with high levels of growth but low levels of female schooling. They argue that the puzzling finding of female education inversely affecting economic growth is driven by these outliers since excluding them leads to insignificant results. Lorgelly and Owen (1999) are not convinced by Barro and Lee's argument of "backwardness" and conclude that their findings are sensitive to their sample. This is confirmed by several other empirical studies whose outcomes suggest that gender inequality in educational access and attainment contributes to a decrease in economic welfare. King and Hill (1993) construct a panel dataset including 152 developing countries and examine the effect of women's education on child and maternal health, fertility, and economic growth. Their findings show that a low female to male ratio is associated with lower GDP per capita and that the amount of women's education positively influences family well-being and economic growth. In a later cross-country study, Hill and King's (1995) results confirm their previous findings, namely that an increase in women's education fosters economic growth and also contributes to other social benefits including a rise in the average life expectancy of the population as well as an improvement in the functioning of political processes. Dollar and Gatti (1999) run an OLS regression on a panel including 127 countries, covering the period from 1975 to 1990, and conclude that gender inequality in education, which is calculated on the basis of secondary education enrollment rates, inversely affects economic development. They control for endogeneity by using civil liberties and religion variables as instruments for male and female education. Knowles et al. (2002) examine the long-run effect of female education on economic growth by extending the Solow Growth Model in which they consider male and female education, proxied by average years of schooling, as separate factors of production with diminishing returns. Results suggest that gender gaps in education have a large negative impact on the level of GDP and underline the importance of gender equity in education by demonstrating that female education contributes to a rise in labor productivity. (Klasen 2002; Abu-Ghaida and Klasen 2004; Klasen and Lamanna 2009) conduct various longitudinal studies taking into account different world regions (the Middle East and North Africa, sub-Saharan Africa, South Asia) and conclude that gender inequality reduces economic growth in the countries studied and that the strongest effects seem to be in sub-Saharan Africa. Blackden et al. (2007) refer to the existence of an indirect link between gender inequality in education and economic growth. They argue that low female education, as a result of educational gender inequality, leads to higher fertility and child mortality rates as well as higher malnutrition rates and low investment into children's education, which in turn increases poverty and negatively affects economic development. Thevenon and Del Pero (2015) assess the contribution of female human capital to economic growth in 30 OECD countries during the period 1960-2008. Using longitudinal cross-country data on educational attainment, they find that an increase in women's educational attainment relative to men's positively affects per capita growth and that the size of the impact has been higher for the most recent years. Estimated regression coefficients across different sub-periods of the sample show robust results, holding even when countries with an above-average increase in years of education are excluded from the analysis.

While existing studies have focused on more recent trends in educational gender disparities and their impacts on economic performance, our study applies a path dependence approach aiming to analyze the link between historical gender gaps in schooling and today's economic outcomes in sub-Saharan Africa. More precisely, we contribute to the literature by examining the following questions: First, in what way do long-standing educational gender gaps during the 20th century play a role in today's economic performance of sub-Saharan African regions? Second, do African regions draw economic benefits from having kept girls' schooling at relatively low levels or would an increased investment in female education have been a more efficient economic choice?

The repeated cross-sectional design of this cohort study allows us, in contrast to previous research on this topic, to go back in time until the early 20th century and therefore to examine whether today's economic activity in sub-Saharan African regions is inter alia path-dependent on educational gender disparities, prevailing during the past century. Numerous persistence studies have shown that history matters for current economic and social outcomes. For instance, we now know that historical medical campaigns against sleeping sickness, which were forcibly conducted by the French colonial government in Central Africa still have negative effects on the population's trust in medicine today (Lowes and Montero 2021). Similarly, the Tuskegee study by Alsan and Wanamaker (2018) shows that withholding treatment for syphilis from black men between the 1930s and the 1970s led to a greater mistrust in medicine among black men, who consequently suffer from higher rates of preventable mortality today. Other famous studies (Acemoglu et al. 2002; Nunn 2008) trace today's state of economic development in African and American regions back to historical events. For instance, Nunn (2008) finds that the transatlantic slave trade which occurred between the 16th and 19th century still has negative effects on the state of Africa's development. Acemoglu et al. (2002) argue that European colonizers who settled in poor Latin American regions during the 1500s implemented good institutions which encouraged investment, eventually allowing poor regions to outgrow regions, which were relatively rich during the 1500s and are now relatively poor (reversal of fortune).

While there is no doubt that path dependence can play a considerable role in economic development, it is essential to understand how history matters. Timing is an important dimension to a study's findings because the nature and existence of long-term effects largely depend on the timeframe considered. Since persistence should be examined at different points in time to draw generalizable conclusions, we analyze the persistence of the educational gender gap across several birth decades during the past century. To the best of our knowledge, this is the first persistence study investigating the relationship between gender inequality in education and economic development in sub-Saharan Africa at the sub-national level, using nighttime light data as a proxy for economic output. Basing our repeated cross-sectional analyses on a sample of 5,322 observations, including cohorts born between the 1920s and the 1970s, in 1,107 regions within 19 African countries, we observe that the long-term persistence of educational gender disparities over the past century is negatively associated with economic development in sub-Saharan Africa. In addition, we find evidence that an increase in girls' education is positively correlated with economic output per capita in the long run.

This study is structured as follows: Section 2 introduces satellite-recorded nighttime light data which we use as a proxy for regional economic output. Section 3 examines the theoretical linkages between educational gender inequality, female education, and economic performance. Section 4 gives an overview of potential factors influencing economic activity.

Section 5 describes the data and empirical methodology used. Section 6 presents the results followed by a discussion. Section 7 assesses the validity of our results. Section 8 concludes.

C.2. Nighttime lights as an innovative proxy for economic growth

GDP is widely recognized as one of the most important indicators of economic growth. While GDP data are available for almost all countries in the world, mostly at a national and sometimes at the state level, it fails to measure economic growth patterns of smaller areas. Due to the lack of a global indicator that allows researchers to measure economic output at the regional or local level, there is demand for an alternative statistic that enables us to assess economic development at a disaggregated level across time and space. In recent years, a growing number of scholars have been exploring alternatives to GDP and have discovered that proxies based on satellite nighttime light images inter alia are useful to measure economic activity. Two major studies (Chen and Nordhaus 2011; Henderson et al. 2011) undertook a formal analysis comparing proxies based on nighttime light data to standard economic development measures (i.e., gross domestic product). Results confirmed that nighttime lights are measured with consistent quality and can be used to proxy economic activities at sub-national levels, whereupon further economic research papers followed, using nighttime light data extensively (Henderson et al. 2012; Michalopoulos and Papaioannou 2013, 2014; Pinkovskiy and Sala-i-Martin 2016).

How can we use satellite-recorded nighttime light data as a proxy for economic activity? Nighttime lights, which are observed from space at night, result from human activity. The rationale behind this proxy variable is that higher economic performance boosts human activity, and since light is a necessity for the vast majority of goods consumed at night, the underlying assumption is that light consumption per capita increases with a rise in income. While satellite nighttime light data can be applied in multiple fields, for instance, to measure urbanization (e.g., Zhang and Seto 2011; Harari 2020), electric power consumption (e.g., Letu et al. 2010), natural and humanitarian disasters (e.g., Kohiyama et al. 2004; Li and Li 2014), human well-being and development (e.g., Elvidge et al. 2012; Ghosh et al. 2013), poverty and income inequality (e.g., Noor et al. 2008; Elvidge et al. 2009), many scholars have focused on the application of nighttime light data to study economic activity at sub-national levels including regions, districts, etc. Henderson et al. (2012), for instance, implemented a statistical model where they combined data on nighttime lights with data on income growth between 1992-1993 and 2002-2003 to develop better estimates of income growth. They base their analysis on a panel of 188 countries and find that satellite nighttime light data are suitable estimates for economic growth at disaggregated levels when income data are not available. Doll et al. (2000) make use of nighttime light data and purchasing power parity (PPP) to establish a GDP map with a one-degree spatial resolution on a worldwide scale. In a later study, Doll et al. (2006) include 11 European countries and the United States at the sub-national level and find a positive relationship between economic activity observed from nighttime lights and GDP across a range of spatial scales. Bundervoet et al. (2015) focus on sub-Saharan Africa and analyze the correlation between nighttime light data provided by the Defense Meteorological Satellite Program (DMSP) and GDP data from the World Development Indicators (2013) for 46 sub-Saharan African countries between 1992 and 2012. Based on this sample with a total of 966 country-year observations, the authors find a fairly high correlation between country-level GDP and nighttime light data. They consequently estimate economic growth for 47 counties in Kenya and 30 districts in Rwanda using nighttime light data. Michalopoulos and Papaioannou (2013, 2014) study the impact of institutions on regional development within African countries and make use of satellite-observed nighttime lights to measure regional variation in economic performance. However, it should be acknowledged that more recent studies remain skeptical of the use of nighttime light data as a proxy for sub-national activity. Addison and Stewart (2015) conclude, based on their sample, that the DMSP nighttime light data are quite noisy and therefore not suitable to measure output growth over time. Mellander et al. (2015) argue that the positive relationship between economic activity (especially when measured by income) and nighttime lights is to some extent overestimated in very densely populated areas and underestimated in rural areas. Bickenbach et al. (2016) analyze nighttime light data at the regional level for the emerging countries Brazil and India as well as for developed economies including the United States and Western Europe, and their results show that the correlation between nighttime light growth and actual GDP growth is not constant across regions. Despite being aware that nighttime light data are not free from measurement errors, Hu and Yao (2022) consider these data to be important for improving GDP measures, especially in developing countries with poor statistical systems where GDP data are either unavailable or inaccurately measured, or where the existence of an informal economy may lead to uncertainty in real GDP measures (Chen and Nordhaus 2011, 2015; Henderson et al. 2012). Using a production function, Hu and Yao (2022) identify the brightness of nighttime lights for a given amount of GDP, which allows them to infer the distribution of the actual GDP from the observed joint distribution of official GDP data and nighttime lights. Finding that official GDP measures are less accurate for low and middle-income countries, Hu and Yao (2022) suggest relying on nighttime light data to improve these measures.

In our study, we make use of both nighttime light data at the level of sub-Saharan African birth regions and actual GDP per capita data at the highest administrative level, which we derive from Gennaioli et al. (2013) to support our results. Having introduced the nighttime light indicator as a proxy for economic performance, we now turn to the discussion of the relationship between gender inequality in education and economic development.

C.3. Underlying theory between gender gaps in education and economic performance

Although it is widely documented that human capital positively affects economic growth, only a limited number of studies have analyzed the relationship between education-based gender differences and economic performance. In which ways do educational gender disparities affect economic output per capita? It is natural to assume that the innate aptitudes of boys and girls are similarly distributed across both genders and that individuals with more inherent talent are more likely to be educated (Klasen 2002). The existence of gender inequality in education, therefore, means that more boys with less ability receive education compared to gifted girls, resulting in lower average innate abilities of children than if boys and girls had the same chances of acquiring education. Under the assumption that human capital does not only consist of skills acquired through education and at work but also of innate abilities, gender inequality in schooling hence first leads to a decrease in innate abilities and consequently to a decrease in the average level of a society's human capital, negatively affecting the economy's performance (Klasen 2002). Following the same logic, gender-based disparities in education would therefore also weaken the effect of male education and increase the impact of female schooling on economic performance (Dollar and Gatti 1999; Knowles et al. 2002).

Similarly, the average level of human capital declines when considering male and female human capital as imperfect substitutes. In this case, lower average human capital stems rather from higher male education, which generates decreasing marginal returns to education than from the selection of males with lower innate abilities, also hampering economic growth (Knowles et al. 2002). These theoretical claims are confirmed by empirical studies (Hill and King 1995; King and Mason 2001), whose findings show higher marginal returns to the education of girls than boys, which is likely due to this selection effect and diminishing returns to male education.

Working towards a decrease in gender-based inequality in schooling by fostering female education may exert direct and indirect effects on economic development. According to King and Mason (2001), female education positively affects the quantity and the quality of education that children receive. Subsequently, a better educated next generation with higher average human capital boosts the productivity of workers, positively contributing to economic development. Additionally, it is acknowledged that similar education levels within households have positive externalities on educational quality. Klasen (2002) states that if siblings do have the same level of education, they will be able to mutually strengthen each other's educational process and success. Hence, supporting girls' education may positively contribute to these effects. The same is valid for partners. Being equally educated allows them to foster and encourage the gain of new knowledge throughout their lives and consolidate their acquired educational skills. The development of greater human capital through such channels can directly affect positive outcomes in economic development since it allows workers to increase their productivity. Furthermore, there is evidence that countries, which fully exploited the potential of their female population and consequently accumulated sufficient human capital became "superstars", as Baten and de Pleijt (2018) put it, in long run development.

Some scholars (e.g., King and Hill 1993; Blackden et al. 2007) go beyond analyzing direct influences of educational gender inequality on economic growth and also emphasize indirect channels, notably, demographic effects. Evidence indeed shows that lower educational gender inequality achieved through a rise in female education leads to lower fertility rates, which in turn positively influences economic outcomes. Bloom and Williamson (1998) argue that lower fertility levels will lead to a favorable demographic constellation in the long run since a decline in fertility slows population growth, while the working-age population remains large because of previously high fertility rates. Consequently, more capital per worker will be available (capital deepening) as compared to capital widening, where additional workers are equipped with capital. It further means that the dependency burden is low, which Bloom and Williamson (1998) refer to as a "demographic gift", allowing for increased saving rates and positively affecting per capita income. Although we will mainly focus on analyzing the direct effects of educational gender inequality on per capita output in this study, we also test for the occurrence of indirect externalities operating through fertility effects.

C.4. Correlates of economic growth

Previously, we explained the theoretical linkages between our two main independent variables of interest (i.e., educational gender inequality and female education) and our dependent variable, economic output per capita, measured by nighttime light data. Only a few theoretical growth models (Galor and Weil 1996; Lagerloef 1999; Knowles et al. 2002) take into account gender inequality in education and examine its correlation with economic growth. Empirically, studies find some evidence that while educational gender disparities reduce economic performance (Hill and King 1995; Dollar and Gatti 1999; Klasen 2002; Abu-Ghaida and Klasen 2004; Klasen and Lamanna 2009) fostering girls' education is positively associated with economic growth (Hill and King 1995; Thevenon and Del Pero 2015). In this section, we discuss further potential determinants of economic development, which we use as control variables in our analysis.

Educational expansion. During the past century, sub-Saharan Africa underwent a substantial schooling revolution, which came along with a sustained expansion of education across African regions. While primary school enrollment rates increased from 6 percent in 1910 to 78 percent in 2018, the average number of attained years of schooling rose from 0.2 in 1900 to 5.7 in 2010 (Barro and Lee 2015; Baten et al. 2021). Human capital formation is one of the most important economic growth factors that can help to develop an economy. Countless studies confirm this central finding for sub-Saharan African countries (Mankiw et al. 1992; Barro and Lee 1994; Bloom et al. 2006; Gyimah-Brempong et al. 2006; Gyimah-Brempong 2011; Kanayo 2013; Ogundari et al. 2018)

Trading location. Various studies suggest that geographic features do play a role when it comes to economic development. For instance, Sachs and Warner (1997), as well as Gallup, Sachs and Mellinger (1999), find evidence that landlocked regions in sub-Saharan Africa, which face high transport costs of international trade because they are located far from the sea, suffer from poor growth performance. Cohen et al. (1997) state that sub-Saharan African regions do have a greater inland population (79 percent) than the global average (50 percent) and conclude that coastal regions have a GDP per capita 1.35 times the world average while the GDP of interior regions make up only 0.65 times the world average. This relatively large difference may be explained by the opportunity of coastal regions to engage in a wide scope of sea trade, drawing economic benefits from it.

Colonizer identity. Until the late 1950s sub-Saharan African countries were mainly colonized by the British and the French. Literature shows that former British colonies had a better economic performance than former French colonies (Grier 1999; Bertocchi and Canova 2002), especially during the colonial and postcolonial periods. Agbor (2015) studies 36 sub-Saharan African countries for the period 1960-2000 and attributes the faster economic development of British colonies to the positive externalities of the British education system during the colonial period. Similarly, Bolt and Bezemer (2009) argue that the educational lead of British colonies is at the source of their faster growth and that human capital plays a key role in explaining growth disparities between African countries in the long term. Cappelli and Baten (2021) study the correlation between colonialism and human capital development in Africa from the early 18th to the late 20th century and find that the overall positive marginal effect of colonialism on numeracy is driven by the British education system.

It is well documented that the educational policies implemented between the two colonial administrations differed substantially, as did their goals. The British were interested in cost-effective schooling and therefore engaged voluntary agencies, in particular Protestant, Anglican, and Catholic mission schools for the provision of education. They were tolerant towards all kinds of denominations and their attitude towards Christian missionaries was mostly driven by the laissez-faire principle, which means that mission schools had substantial flexibility in how they operated schools, recruited teachers, taught the gospel, etc. (White 1996; Frankema 2012). The aim of British missionaries was to win religious converts and since education was the key to attracting people (Berman 1974), they provided educational access to a large part of the population (Dupraz 2015). Overall, under the British colonial government the educational system was decentralized (Garnier and Schafer 2006) and adjusted to local conditions (i.e., teachers taught courses in local languages).

In contrast, the French colonial government, pursuing anticlerical sentiments, wanted to keep state and church separated and hence preferred to invest in public schools, which were financed and controlled by the colonial administration (Cogneau and Moradi 2014). Their primary interest was to educate a small group of elites who eventually could be hired into the colonial administration, which is why they neglected primary education at the expense of higher education (Frankema 2012). Aiming at assimilation, French colonizers hired mostly teachers from Europe who gave instructions in French (Agbor 2015), making it more difficult for the indigenous population to follow.

By the end of the late colonial period, French colonies had lower school enrollment rates than former British colonies (Benavot and Riddle 1988; Brown 2000), a trend that seems to have been long-lasting. According to Garnier and Schafer (2006) by the year 2000, the enrollment rates of primary school children constituted 70 percent in former British colonies, whereas in former French colonies, only 55 percent of school-aged children were enrolled in primary school. Moreover, Mingat and Suchaut (2000) report that the number of children completing school is higher in former British than in former French colonies, with fewer repeated years.

Christian missions. A number of studies show that Christian mission activities mainly affected long-run economic development indirectly, via human capital, since missionaries arguably played an essential role in building schools, driven by the motivation to provide access to the scriptures through literacy (Woodberry 2004; Becker and Woessmann 2009; Nunn 2010; Frankema 2012). Using protestant missionary activities in the early 20th century as an instrumental variable for human capital, Acemoglu et al. (2014) find returns in the range of 25-35 percent in terms of one additional school year on GDP per capita today. Protestant missionaries also introduced the printing press in sub-Saharan Africa in the 19th century, whose long-term impact is analyzed by Cagé and Rueda (2016). Their findings show that the introduction of the printing press had positive long-term effects on contemporary civic and social capital, leading to higher economic performance and wellbeing.

Cash crop and mineral production. Another potential factor influencing regional development is the export of cash crops. Findings show that the production and export of cash crops come with substantial wage and employment opportunities, especially in rural areas. Africa’s cash crop agriculture, starting in the late 19th century, has boosted agricultural innovation over time by raising income that in turn allowed for further agricultural investment while establishing institutions, which have accelerated commercialization (Achterbosch et al. 2014). Li et al. (2018) explore the socio-economic and ecological consequences of cash crop cultivation and find that the production and export of cash crops do not only benefit the rural economy but also attract foreign investment, exerting positive influence on economic development.

Literature on the effects of natural resources on economic performance is not conclusive. Economies with significant mineral endowments can be found at both ends of the UNDP’s Human Development Index, at the top and at the bottom. While a number of empirical studies conclude that the wealth of minerals and natural resources have adverse consequences on economic growth (Bruno and Sachs 1982; Sachs and Warner 1995, 1997, 2001; Auty 2001), others find that natural resources and minerals may affect economic output through both negative and positive channels, acting as either a curse or a blessing (Stijns 2005; Van der Ploeg 2011). Using OLS and 2SLS estimations Brunnschweiler (2008) fails to find evidence for the resource curse hypothesis. Instead, her findings show a direct positive influence of mineral resources on real GDP growth for the period 1970-2000. Similarly, using panel fixed effects, Smith (2015) evaluates the impact of natural resource discoveries since the 1950s on economic performance and finds positive effects.

Infrastructure. Infrastructure investment has proven to be another potential driver of economic development in the long run. Fedderke et al. (2006), for instance, focus on the impact of infrastructure investment (roads, transportation, and housing) on economic growth in South Africa, considering the time period 1875-2001. Their findings show that investment in infrastructure boosts economic performance directly but also indirectly by raising the marginal productivity of capital. Similarly, Jedwab and Moradi (2013, 2016) analyze the long-term impact of infrastructure investment on economic growth in sub-Saharan Africa and therefore explore the effects of colonial investments in railroads. Their findings show that rail construction during colonial times had persistent positive effects on Africa's long-term economic development and point out the existence of path dependence: Regions, which had early access to railroads during colonial times are more developed today. Positive externalities remain despite these railroads have been replaced by other means and investment has become obsolete.

Tsetse fly. Alsan (2015) explores inter alia linkages between current African economic performance and the tsetse fly, which can be only found in Africa. The tsetse fly, preferentially feeding on animals but also on human blood, can cause serious economic losses in livestock, consequently hampering economic development. Alsan's findings show that African regions with relatively high tsetse suitability suffer from lower economic performance and a significant decline in cattle.

Population density. The relationship between economic output and population density has been debated among economists for centuries. Malthus (1798) developed a formal framework, which regards population growth as the main obstacle to increases in income, explaining that higher living standards lead to larger but not wealthier populations. More than 200 years later, economists still debate about inconclusive results. Findings of several studies show a negative impact of population density on economic growth (Mankiw et al. 1992; Kelley and Schmidt 2001; Klasen and Lawson 2007). Similarly, some scholars conclude that exogenous demographic shocks such as the Black Death, lead to a decline in population, resulting in a rise in income (e.g., Voigtlaender and Voth 2013). Conversely, results from other studies show that population growth causes an increase in income. Kremer (1993), for instance, suggests that all members of a society have the opportunity of making a scientific discovery, which can benefit the entire community without much cost thereafter. He argues that the probability of an individual making such a discovery increases with the population size.

Initial economic development. When measuring a region's economic performance, an important factor that needs to be accounted for is its initial stage of economic development. Literature has shown that today's economic performance of an economy depends to a large extent on its initial GDP (e.g., OECD 2002; Barro 2003). Some evidence shows that the roots of today's differences in economic development across regions date back to the colonial period when colonizers engaged in various economic activities leading to different growth trajectories (Engerman and Skoloff 2002).

Labor migration. Little literature has surfaced on the economics of colonial migration in sub-Saharan Africa, mainly due to a lack of data. Migration was driven by labor requirements for plantation work and the construction of infrastructure (Ziltener et al. 2017; Amin 2018). In addition, the expansion of cocoa farming and mining as well as the growing export of products created a demand for labor (Adepoju 1995). Ziltener et al. (2017) argue that labor migration was predominant in areas, which were colonized for a longer period of time and were characterized by a high degree of trade concentration as well as a strong presence of Christian missionaries. They explain that the migration of workers was encouraged by means such as opening markets and the provision of permits for agencies, etc. Migrant domestic workers, as a part of colonial legacies, might have positive externalities on economic growth mainly via the building of infrastructure and the expansion of cash crop exports, although we do not find collinearity in our sample.

Democracy. A further factor that may influence the economic development of a region is its form of government. From a theoretical perspective, three main hypotheses concerning the relationship between democracy and economic growth have been established (Sirowy and Inkeles 1990). The conflict hypothesis suggests that democracy prevents economic growth and is less conducive to long-term development (Barro 1996) inter alia because democratic regimes fail to implement policies allowing for rapid growth (Sirowy and Inkeles 1990) and tend to support income redistribution policies between the rich and the poor. The compatibility hypothesis states the opposite, namely that democratic regimes, which allow for political pluralism, limit rent-seeking behavior (De Haan and Sturm 2003), protect property rights

(North 1993), and reinforce political and economic freedoms (Friedman 1962) are essential for economic growth. The third perspective, known as the skeptical hypothesis, argues that the relationship between democracy and economic growth is not systematic. Empirically, scholars find mixed results. While Huntington and Dominguez (1975), Marsh (1979) and Landau (1986) find negative effects of democracy on economic growth and, hence, evidence for the conflict hypothesis, McGuire and Olson (1996), Niskanen (1997), Lee (2003), Gradstein (2007) and Shen (2007) find a positive impact, supporting the compatibility hypothesis. According to Feierabend and Feierabend (1972), Dick (1974), Russett and Monsen (1975), Meyer et al. (1979), and Marsh (1988) there is no clear evidence that democracy affects the pace of economic growth, which is in line with the skeptical hypothesis.

Civil violence and civil war. Internal violence and civil wars have also proven to affect a region's economic performance; however, existing evidence is not conclusive. According to Rasler and Thompson (1985), any kind of war generates a mixture of destructive and constructive effects and may therefore have a negative, positive, changing, or insignificant net impact on economic growth. Yet, when it comes to civil wars, a number of studies find them to be destructive to economic performance. Rodrik (1999) attributes the lack of persisting growth rates to domestic conflicts. Collier (1999) argues that civil wars destroy natural resources, leading to a decline in GDP. Artadi and Sala-i-Martin (2003) show that civil conflicts caused the average annual growth rate in sub-Saharan Africa to decline by 0.5 percentage points in the second half of the 20th century.

Life expectancy. Finally, linkages between life expectancy and economic output have been widely studied by economists. It should be mentioned upfront that the inclusion of life expectancy in our analysis could be considered a bad control based on the argument that it could act as a channel between educational expansion, one of our main explanatory variables, and economic output, our dependent variable since better educated individuals tend to adopt a healthier lifestyle. However, we consider a potential omitted variable bias in the case of non-inclusion as a bigger caveat, which is why we account for life expectancy. Theoretically, an increase in longevity may affect per capita income either positively or negatively. While a decline in mortality may lead to more efficient human capital (since higher life expectancy provides incentives to invest in education) positively affecting economic output, it may also cause a rise in the population size. However, with the exception to Acemoglu and Johnson (2007), empirical investigations generally find evidence that higher life expectancy and better population health foster economic growth (Bloom et al. 2004; Well 2007; Aghion et al. 2010;

Bloom et al. 2014).

Having discussed the potential determinants of economic development we account for in this study, we will now move to the data section.

C.5. Data and methods

Our cohort study comprises a set of 19 sub-Saharan African countries (Benin, Botswana, Burkina Faso, Cameroon, Ethiopia, Ghana, Guinea, Kenya, Lesotho, Liberia, Malawi, Mali, Rwanda, Senegal, Sierra Leone, South Africa, Tanzania, Uganda, and Zambia), 1,107 administrative birth regions and is based on 5,322[30] observations.

To analyze the impact of prevailing gender inequality in education during the colonial and post-colonial periods on current per capita economic output in African regions, we extend the database used in Baten et al. (2021).[31] This database was constructed based on aggregated data of 15.8 million individuals, aged between 25 and 80 years, who were born between the decades 1920 and 1970[32]. Hence, our repeated cross-sectional analysis covers a time span of 60 years. The birth regions[33] of individuals correspond to either first- or second-level geography[34] and constitute our unit of observation, together with the time dimension of the respective birth decade. Table C.1 presents the descriptive statistics of all variables used in this study.

C.5.1. Measuring regional economic activity with nighttime lights

To measure regional economic activity in sub-Saharan Africa, our dependent variable, we use nighttime light data provided by the National Oceanic and Atmospheric Administration (NOAA

[30] Table C.9 in the Appendix gives an overview of the number of birth regions and observations per country and census year included in our sample.

[31] A detailed description of the dataset and variables included can be found in the Appendix (C.11.1. - C.11.4.)

[32] Table C.10 in the Appendix provides an overview of the sample construction.

[33] In our analysis, we consider the birth region of individuals instead of their region of residence as a cross-sectional unit of observation. The reason behind this is that at the time of the census enumeration, a certain (unknown) share of residents in a district may have migrated there earlier in their life. It is generally known that migration is highly age-, skill- and sex-selective. Analyzing the level of educational attainment by districts of residence would therefore reflect this compositional effect rather than the spatially uneven educational opportunities for boys and girls, assuming that children complete most of their education in the districts where they are born.

[34] Countries are divided into administrative divisions, which have various geographic levels. In our sample, we use either first or second-level administrative divisions, whereby the first-level corresponds to the largest administrative subdivision of a country.

2020). Nighttime light data are based on satellite images collected by the Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) sensor. Every night, between 8:30 and 10:00 pm local time, the satellites observe every part of the earth. The National Oceanic and Atmospheric Administration (NOAA) processes these satellite images and removes cloud-covered images, summer months when the sun sets late, auroral activity, and forest fires. Consequently, the yearly average value of nighttime lights observed by a respective satellite is calculated across all valid observations. NOAA provides three different versions of nighttime light data, which are publicly available for research: stable lights, the average lights x pct (saturated lights that contain detections from fires and other background noise), and radiance-calibrated lights. Like most scholars, we rely on the stable lights for our analysis, which are available for a period of 22 years between 1992 and 2013. Stable lights depict the relative intensity of lit areas. Non-lit areas have been set to zero and ephemeral lightning events i.e., fires have been removed from the stable light products. Therefore, stable lights allow us to see exclusively man-made lights in the different parts of the world, excluding all sources of natural lights and lights deemed transient.

The satellite-year specific nighttime light data come in grid files with pixels 30 * 30 arc seconds whereby each pixel corresponds to a geographic location of less than one square kilometer (0.86). This allows us to map nighttime light data observed from space on small squares and aggregate them to the level of the sub-national unit we want to study, namely sub-Saharan African birth regions. Existing evidence shows that nighttime light data provided by NOAA strongly correlate with official output measures at various levels, including countries (Henderson et al. 2012), provinces (Holder and Raschky 2014a, 2014b), and grid cells of 1° x 1° i.e., 100km x 100km near the equator (Chen and Nordhaus 2011, 2015).

Based on our data, Figure C.2 shows the correlation between nighttime light intensity per capita and GDP per capita, whereas Figure C.3 shows the relationship between nighttime light intensity per area (measured in km^2) and GDP per capita at the country level. For both nighttime light specifications, we find a strong positive correlation with GDP per capita data which we obtain from the World Bank (2013). Figure C.4 presents the distribution of GDP data and Figure C.5 the distribution of nighttime light data at the country level on the map. We observe higher nighttime light intensities for countries with a relatively higher per capita GDP (darker grey areas) including South Africa, Botswana, Zambia, and Ghana. In contrast, countries with lower GDP per capita levels, for example, Ethiopia, Malawi, Guinea, and Uganda also show lower nighttime light intensities (lighter grey areas).

The average light intensity for each nighttime light pixel is reported by a digital number (DN) ranging from 0 to 63 on a worldwide scale. While zero means no illumination, at 63 nighttime light brightness is saturated. One common caveat with the top-coded pixels is that densely populated areas, including big cities and metropoles, do not appear brighter than mid-sized towns due to sensor saturation, leading to distorted estimates of regional inequality and convergence. Indeed, since a higher light intensity than 63 DN cannot be captured, the differences between rural and urban areas are understated, which in turn leads to an understatement of inequality and overstated convergence. However, only a tiny fraction of pixels (0.1 percent), in wealthy and densely populated areas, take the value 63 (Henderson et al. 2012). Out of these 0.1 percent, less than 0.06 percent concern African countries (Bruederle and Holder 2018). In our sample, the nighttime light intensity values (DN) range from 0 to 58. Therefore, we do not regard top-coding as a major issue for our study. In fact, our concern is rather the opposite. Given the relatively high share of zero values in the stable lights data, we may actually underestimate economic performance in more rural or poorer African regions where still some economic activities take place, which we may not be able to capture with stable nighttime light data. We deal with this issue as best as possible by adding a small constant to the zero nighttime light pixels and we normalize nighttime lights by population.

Since we are interested in analyzing the long-term effects of gender gaps in education on current economic activity in sub-Saharan Africa, we use stable nighttime light data from 2013, the most recent year available. Figure C.6 shows the dispersion of our nighttime light data in sub-Saharan Africa at the sub-national level of birth regions. Based on the rationale that educational gender disparity may more likely affect the level of GDP (King and Hill 1993, 1995; Knowles et al. 2002) than its growth rate and because of previous findings, which show that nighttime light data are not suitable for measuring economic growth over time (Addison and Stewart, 2015), we only take cross-sectional stable light data into account. Aggregating these data at the spatial unit of birth regions, we construct our dependent nighttime light variable following Hu and Yao (2022) and Henderson et al. (2012). We use two different specifications for our dependent variable. Since we are not only interested in measuring the overall wealth of a birth region but per capita income, we use nighttime light intensity per capita as our main specification, whereby we aggregate the sum of all DN values of nighttime lights within a birth region, normalized by population. Population data (2013) come from the LandScan population distribution database. As an alternative, we construct our nighttime light per area measure for which we calculate an average DN value of all nighttime light pixels per area, measured in square kilometers.

C.5.2. Measuring educational gender inequality and female education

Data used to construct our main independent variable of interest come from the Integrated Public Use Microdata Series International (IPUMS-I). To measure educational gender disparity in our main analysis, we consider the absolute gender gap by calculating the difference between the average male and female years of schooling completed per birth region and birth decade. A positive number, therefore, indicates that men have acquired more years of schooling than women and a negative number the contrary. As a robustness measure, we also construct the educational gender ratio, which we obtain by dividing average male years of schooling completed by average female years of schooling completed. A ratio of 2, for instance, points out that men have acquired twice as much education as women, whereas a ratio below 1 indicates that women received more education than men. Depending on the measure used, a different perspective is provided. While the educational gender ratio (relative measure) allows us to analyze to what extent education is skewed towards men or women, providing diminishing returns to education, the educational gender gap (absolute measure) considers the difference in actual numbers of school years between men and women, implying constant returns to education.

Figure C.7 shows the evolution of educational gender inequality in sub-Saharan Africa during the 20th century at the sub-national level. Overall, after having controlled for male educational expansion, we notice an increasing trend in educational gender disparities for most countries until the mid-20th century, which constitutes the tilting point, followed by a decline thereafter. Zooming in, we clearly observe within-country differences in terms of educational provision being shared between males and females. In Ghana and Kenya, for instance, gender disparities varied considerably across regions, especially during the 1950s when gender inequality was peaking. While the northern regions of both countries benefited from more gender equality, the southern part was exposed to higher gender disparities, exceeding 2.5 years. In contrast, South Africa, Burkina Faso, and Mali which had relatively low educational gender gaps in all three periods, as well as Botswana and Lesotho, two countries where gender disparities were in favor of women, did not seem to have experienced much variation across their sub-national regions.

Although sub-Saharan Africa underwent a genuine schooling revolution during the 20th century, which came along with a substantial decline in educational gender inequality, 12 out of the 17 countries on a global scale, which have not yet achieved gender parity in primary schooling are located in sub-Saharan Africa (UNESCO 2020), leaving this world region with a poor and erratic record of economic growth. Based on all countries included in our sample, Figure C.8 displays the correlation between the educational gender gap during the mid-20th century, where gender inequality was the highest, and current economic performance, proxied by nighttime light intensity per capita. Although the correlation coefficient varies in terms of magnitude, we clearly observe a negative correlation trend for all countries included in our sample, requiring further investigation into this negative association between educational gender gaps and regional per capita GDP in a regression framework.

To measure female education, our second main variable of interest, we obtain data on female years of schooling completed from IPUMS-I. First descriptive analyses displayed in Figure C.9 show evidence of an overall positive correlation between the investment in girls' education and economic development at the regional level, for some countries being stronger than for others.

C.5.3. Control variables

As discussed in the previous section, we account for a set of relevant factors, which play an important role in economic development. A precise description of these variables, their construction, and data sources can be found in the Appendix.

C.5.4. Methodology

We apply a Repeated Cross-Sectional (RCS) Design to undertake a path dependency analysis. Firstly, we examine the association between the long-term existence of educational gender gaps during the 20th century and current economic development in sub-Saharan Africa. Secondly, we focus on fostering female education and analyze whether sub-Saharan Africa would have drawn economic benefits from a greater investment in girls' schooling.

A persistence study usually determines the effect of an explanatory variable X at time t on an outcome variable at time $t + z$, where z represents the time difference and can range from only a few years to millennia. We run six sequent cross-sectional regressions, one per birth decade, considering the timeframe 1920-1979 for our independent variables and the year 2013 for our dependent variable, nighttime light intensity per capita. Using the Generalized Spatial Two-Stage Least Squares (GS2SLS) estimator we run two spatial autoregressive (SAR) models, one where we use the educational gender gap *(male yrsc – female yrsc)* as our main variable of interest and one where we use female education *(female yrsc)* as our main variable of interest.

Regression equation: model 1

$$log\, nighttime\ lights\ pc_i = \rho WY_i + \beta 1 gapyrsc_{it} + \beta 2 maleyrsc_{it} + X_{it}\Gamma + Z_i\gamma + \mu_r + \varepsilon_{it}$$

Regression equation: model 2

$$log\, nighttime\ lights\ pc_i = \rho WY_i + \beta 1 femaleyrsc_{it} + X_{it}\Gamma + Z_i\gamma + \mu_r + \varepsilon_{it}$$

where the dependent variable *log nighttime lights pc* for the year 2013 proxies current economic per capita output, *gapyrsc* measures educational gender disparities at an absolute level, in the administrative region *i* during the considered birth decade *t*. In our repeated cross-sectional regression framework, *t* respectively corresponds to the decades 1920, 1930, 1940, 1950, 1960, and 1970. *Maleyrsc* measured by male years of schooling completed accounts for educational expansion in region *i* during the birth decade t. X_{it} is a vector of factors varying over time (i.e., cash crops, endowment of minerals, access to railroads, population density, migration of workers, democracy, civil war, and life expectancy), which as previously discussed, potentially influence economic output and Z_i comprises all time-invariant controls including trading location, colonizer identity, Christian missions, tsetse fly suitability and cities 1920. In the second model specification, our main variable of interest *gapyrsc* is replaced by female years of schooling completed, *femaleyrsc,* which allows us to look at the correlation between investment in female education, and economic development. To avoid multicollinearity problems, we exclude the variable *maleyrsc* from the second model since it is almost perfectly correlated with *femaleyrsc*. The term μ_r captures regional fixed effects. We account for spatial autocorrelation. Kelly (2019) emphasizes the issues of severe spatial autocorrelation in residuals leading to inflated t-statistics, especially occurring in persistence studies. Therefore, we make use of the Spatial Autoregressive (SAR) Model, controlling for the potential effects that the variation in the explained variable of neighboring birth regions may have on birth region *i*. ρ, therefore, measures the potential spillover effects of nighttime lights from adjacent administrative regions on birth region *i*. Our estimates of ρ are partially significant, indicating that our results are influenced by spatial autocorrelation.

We would like to point out that our study is correlational, and we do not claim causality in our findings. Nevertheless, we believe that they are not coincidental. While we are aware of potential endogeneity issues in our data, (i.e., one could argue that the extent of the educational gender gap and the amount of female education provided depend, at least partly, on the economic performance of a region and wealthier regions are more likely to have a larger number of girls enrolled in school and therefore smaller gender gaps in education) we are able to reduce reverse causality to some extent given the nature of a persistence study, where the outcome Y occurs at a later point in time than the potential drivers X. Indeed, analyzing potential effects of events occurring during the past century (i.e., educational gender gap, female education) on Africa's present-day economic performance allows us to argue that the occurrence of simultaneity is unlikely in our case. That being said, we now turn to the regression results of our repeated cross-sectional persistence study.

C.6. Results

C.6.1. Regression using the educational gender gap as a main explanatory variable

Direct effects

Table C.2 presents the regression results looking at the link between educational gender disparities prevailing during the 20th century and current regional per capita output. While we use the gap in years of schooling completed between men and women (absolute measure) to proxy educational gender inequality in our main specification, Table C.11 in the Appendix shows similar results when using the educational gender ratio (relative measure) instead[35]. We checked for potential multicollinearity amongst predictors and do not obtain values of VIF above 2.5. Our repeated cross-sectional regression model explains, depending on the birth cohort considered, between 39 and 51 percent of the variance in nighttime light intensity per capita. Coefficients for the educational gender gap variable are consistently significant across all analyzed time periods at a 1 percent significance level (5 percent significance level for the latest two birth cohorts) and are negatively associated with the dependent variable. Table C.3 displays the standardized coefficients. We do observe a decline in the magnitude of the educational gender gap coefficient in the second half of the 20th century. While a one standard deviation increase in the educational gender gap is associated with an 8.4 percentage point decrease in nighttime light intensity per capita for the 1920s cohort, for the 1950s cohort, a widening in the gender gap by one standard deviation is correlated with a smaller decline of 6.5 percentage points in economic activity. For the most recent 1970s birth cohort, only a modest

[35] Table C.12 in the Appendix displays the results using nighttime light intensity per area (km^2) as a proxy for economic development.

negative correlation of 2.7 percentage points in economic output per capita can be observed. In terms of educational expansion, an increase in male education is associated with more economic activity per capita across all birth cohorts, with standardized coefficients gradually decreasing from 0.124 for the 1920s birth cohort to 0.084 for the 1970s cohort. With regard to our control variables, results confirm that trading location, as well as the availability of railway infrastructure, plays an important role in economic development. Regions that are located on the coast and regions that had early access to railroads, both seem to benefit from a better present-day economic situation. These coefficients are mostly significant at a 1 percent level. The estimated coast coefficients do not vary much in size but are quite stable across the birth decades considered. On average, being located on the coast is correlated with an increase of 2.7 percentage points in economic output per capita. With coefficients varying between 0.013 and 0.061 having access to railroads during the past century is associated with an average rise of 9.5 percentage points in economic activity today. Positive significant correlations at a 1 percent significance level can also be observed between the endowment of minerals and nighttime light intensity per capita. Compared to other controls, the coefficient sizes of the mineral variable are particularly important, especially for birth cohorts up to the mid-20th century. While a one standard deviation increase in minerals per capita is associated with a 10 percentage point increase in economic output per capita for the 1920s birth cohort, this coefficient reaches around 13 percentage points for the 1940s birth cohort. Our results further show that territories, which were colonized by the French as compared to territories that were colonized by the British are associated with weaker economic performance. We also find some evidence that tsetse-suitable regions are less developed today (Table C.2, columns 5 and 6). For the birth decades, 1920 to 1950, the coefficients of population density also exhibit a highly significant negative correlation with the dependent variable, which weakens gradually and becomes insignificant after the 1950s. Moreover, we find a strong positive correlation between current regional economic output and the existence of cities during the 1920s, our proxy for initial economic development. Throughout most decades these coefficients are significant at a 1 percent level (5 percent significance level for the latest two birth cohorts). Our results also show that regions with a large inflow of migrant workers during the colonial period benefit from better economic performance compared to areas, which had no immigration of workers. Finally, we find that democracy and life expectancy at birth, controls, which we only include for the latest two decades (due to lack of data availability for prior decades) have a positive and statistically significant association with nighttime light intensity per capita. We observe relatively large standardized coefficients for both variables, the economic impact being slightly higher for the

1960s birth cohort. Taking these larger coefficients into account, we conclude that a one standard deviation change towards democracy is correlated with a 28.1 percentage point higher per capita economic output in African regions today, while a one standard deviation increase in life expectancy at birth corresponds to a 20.9 percentage point rise in economic activity.

Indirect effects

Our findings confirm previous research (e.g., King and Hill 1993; Blackden et al. 2007), namely that negative externalities of the educational gender gap also operate through demographic effects. Increased fertility rates, potentially resulting from neglect of female education, are negatively correlated with per capita economic output. In order to understand the extent to which the correlation effect between the educational gender gap and economic performance is mediated through fertility, we follow the approach of Hicks and Tingley (2011) and conduct a mediation analysis. We are interested in analyzing the effect of educational gender inequality on economic development operating via fertility rates. More precisely, we assess how much of the effect of the predictor on the outcome variable is indirect, in other words, transmitted by fertility rates, our mediator variable.

$$\delta_i(t) = Y_i\{t, M_i(1)\} - Y_i\{t, M_i(0)\}$$

Indirect effects are defined for each region *i* as for each treatment status *t*=0,1. δ_i denotes the change in Y_i, the outcome variable (i.e., economic development) corresponding to a change in M_i, the mediator variable (i.e., fertility rate). Holding the treatment status constant at *t*, we take into account the difference between the value of the mediator observed under the control condition, *Mi(0),* and the value that would be realized under the treatment condition, *Mi(1).* If *Mi(0) = Mi(1),* there is no effect of the treatment (i.e., educational gender gap) on the mediator (i.e., fertility rate) and hence the mediation effect would be zero. When both the mediator and outcome variable are continuous, the mediation effect can be expressed by using two linear regressions[36,]

$$M_i = \alpha_1 + \beta_1 T_i + \varepsilon_1 \tag{1}$$

$$Y_i = \alpha_2 + \beta_2 T_i + \gamma M_i + \varepsilon_2 \tag{2}$$

[36] Figure C.10 represents the mediation model graphically.

and taking the product of treatment variable coefficient in regression *(1)* and the mediator variable coefficient in regression *(2)*, i.e., $\beta_1\gamma$.

Having fertility data available for the latest birth decades (1960s and 1970s), we carry out the mediation analysis for each decade separately. Results, presented in Table C.4 show that the percentage of the total effect mediated through fertility is relatively low at just under two percent for the 1960s but increases substantially to almost 19 percent for the 1970s. Controlling for fertility, a widening in the educational gender gap by one year of schooling is associated respectively with a 16.5 percentage point decrease in economic output (column 1) and a 16.2 percentage point decline (column 2). These findings, however, should be interpreted with caution since we do not include further control variables in this part of the analysis.

C.6.2. Regression using female education as a main explanatory variable

Replacing our main explanatory variable, the educational gender gap with female years of education, Table C.5 shows that an increase in female education is positively correlated with our dependent variable, nighttime light intensity per capita. The coefficients of female education are consistently significant at a 1 percent level across all birth cohorts. Depending on the decade considered, this repeated cross-sectional model explains between 39 and 51 percent of the variation in nighttime light intensity per capita. Table C.6 displays the standardized coefficients. While a one standard deviation increase in female education is associated with an 8 percentage point rise in per capita economic output for the 1920s birth cohort, for the 1950s birth cohort, a one standard deviation change in female education results in a 7 percentage point greater level of economic activity. For the latest birth cohort, i.e., individuals born in the 1970s, a one standard deviation increase in female years of schooling completed is correlated with a 9.2 percentage point increase in per capita nighttime lights. We include the same control variables as in our main regression specification but omit male years of schooling to avoid potential multicollinearity problems since this variable is almost perfectly correlated with female years of schooling. The coefficient sizes and significance levels of our controls do not vary much compared to the results we obtain from our main regression specification, presented in Tables C.2 and C.3.

C.6.3. Discussion of results

Which mechanisms could potentially explain the correlation between the various explanatory variables used in our study and the outcome variable, nighttime light intensity per capita? In this section, we will discuss our findings in more depth, starting with the main variables of interest, namely the educational gender gap and female education, followed by the control variables.

Educational gender gap and female education

We study the long-term persistence of educational gender disparities in sub-Saharan Africa and show that educational gender gaps during the 20th century are still negatively associated with current nighttime light intensity per capita, our proxy for economic development in sub-Saharan African regions. Our findings are in line with previous studies by various scholars (Barro and Lee 1994; Barro and Sala-i-Martin 1995; Klasen 2002; Klasen and Lamanna 2009).

One of the main explanations for the negative correlation between educational gender inequality and economic growth provides the selection-distortion effect (Klasen 2002). Indeed, under the assumption that the distribution of innate skills for girls and boys is approximately the same, educational gender inequality implies that more boys who are less skilled than girls get the chance to receive education. This decreases the overall average innate ability, which would be higher if both girls and boys had equal educational opportunities. This misallocation of educational resources leads to lower levels of human capital, eventually resulting in lower economic output (Dollar and Gatti 1999). Taking into account the observed levels of educational gender inequality in Africa, the selection-distortion effect itself could restrict economic growth by up to 0.3 percent yearly (Klasen 2000).

We observe that the size of the regression coefficients for the educational gender gap variable is larger for the early birth cohorts but decreases considerably for the cohorts born in the second half of the 20th century. The reason for this may primarily lie in the increased relevance of other factors during the rise of globalization including for example foreign direct investments (FDIs), international trade, and technological innovation, relative to educational gender inequality. In addition to the emergence of new important aspects influencing economic development, we also observe an overall decline in gender disparities coming along with educational expansion in sub-Saharan African countries after the 1950s. This decline is demonstrated by the educational gender Kuznets curve, representing an inverse U-relationship between the educational gender gap and educational expansion (Baten et al. 2021). Our results further show that an increase in female education for each birth cohort analyzed in this study (1920-1979) is associated with an increase in regional GDP per capita. We argue, based on our findings that an early initial investment in girls' education would very likely have been of benefit for the present-day economic performance in sub-Saharan Africa. As discussed above, a decline in the educational gender gap, which translates into more female education at each level of male education, is likely to exert positive externalities on the quality of overall education. Evidence has shown that female education has a positive impact on the educational outcomes of future generations since educated mothers are able to provide a supportive environment for their children's education (Klasen 2002). Hence, the promotion of girls' education may, via a higher quality of human capital, also positively contribute to a higher economic output per capita.

Besides examining the potential direct effects of gender disparities and female education on economic development, we also apply a mediation analysis to explore potential indirect externality effects operating via demographic effects. Our results show that part of this negative correlation between the gender gap in education and regional GDP per capita (around 19 percent) can be explained by the mediating influence of fertility rates. This finding is in line with Lagerloef (1999) who applies the overlapping generations model (OLG) to explore the interaction between gender inequality in education, high fertility rates, and low overall investments in human capital and economic growth. He argues that initial gender disparities in education can result in a poverty trap by boosting fertility rates and consequently keeping existing gender gaps high, leading to lower economic growth. Working towards educational gender parity, i.e., an increase in female education could contribute to a decline in fertility rates, affecting economic output per capita through the following mechanisms: First reduced population growth promotes economic growth via increased investments that can be used for capital deepening rather than capital widening. This means that the capital-labor ratio increases, allowing for more capital per worker instead of equipping new workers with capital, leading to increased economic output per capita. Second, lower fertility rates lead to a decline in the dependency burden and consequently to higher savings in an economy. Third, over a limited period of time, the working-age population will represent a larger share of the overall population, resulting from previously high fertility rates. This will foster the demand for investment since higher domestic savings are available due to a lower dependency burden. This expansion of investment is also likely to boost economic growth. Fourth, if an economy has the capacity to absorb the growing labor force and offers increased employment opportunities, economic output per capita will increase, even though productivity does not change, and wages remain the same. This can be explained by the fact that a larger proportion of the working-age population shares their income with a relatively smaller number of dependents, resulting in higher per capita income. As previously mentioned, Bloom and Williamson (1998) refer to these last two mechanisms as a "demographic gift", since they have substantially contributed to fast economic expansion in East and Southeast Asia (Young 1995; Bloom and Williamson 1998). However, these effects are only temporary and fade once the working-age population retires and the dependency ratio starts to increase once again since the employment to population ratio will decrease due to lower fertility rates. Even though we do not quantitatively evaluate the effectiveness of each of these mechanisms, it is still important to have clarified the different ways in which lower fertility rates, obtained by an increase in female education, may positively affect economic development.

C.6.4. Controls

Assuming that gender disparities in education can be addressed without reducing male education levels, the use of male years of schooling works well as a proxy for average human capital (Klasen 2002). Therefore, we use male education to control for educational expansion and find that it is positively correlated with nighttime light intensity per capita. Our result is consistent with numerous other studies which find that economic growth is inter alia driven by male education and human capital in general (Barro and Lee 1994; Hill and King 1995; Knowles et al. 2002; Bloom et al. 2006; Kanayo 2013; Ogundari et al. 2018).

In our regression framework, we further account for trading location and infrastructure investment by using coastal location and access to railroads, respectively, as proxies. As expected, based on previous findings (Gallup et al. 1999; Jedwab and Moradi 2013, 2016), our results show that both factors are positively correlated with economic development. Indeed, regions that are located on the coast do benefit from a wider scope of trade opportunities, including maritime trade, which contributes to an increase in economic output. In addition, these regions face lower transport costs compared to landlocked regions, which suffer from less trade and grow more slowly than their coastal neighbors. Similarly, regions that had early access to railroads that were established by African colonizers, mainly for reasons of military domination but also to connect mining and cash crop regions to seaports (Jedwab and Moradi 2016), seem to have developed faster than those which were difficult to reach. Our results show that better-connected regions, which already attracted economic activity during colonial times, have benefited from increased economic growth up to the present day.

Like previous findings (Grier 1999; Bertocchi and Canova 2002; Agbor 2015), our results suggest that territories, which were colonized by the British report stronger economic performance than former French colonies. We can attribute these findings, at least partially, to the different educational policies pursued by the colonizers. While the British colonial education system was more open to competition among mission schools and focused on educating a large part of the population in their native languages, the French colonial government provided education for a small group of elites and restricted, with the implementation of the 1905 law on the separation between the state and church (Cogneau and Moradi 2014), the activities of mission schools.

Further, we control for the presence of minerals. While scholars have found mixed outcomes on the relationship between natural resources and economic growth, our findings support the studies of Brunnschweiler (2008) and Smith (2015). Similarly, we find that the presence of minerals is positively associated with today's economic outputs in sub-Saharan African regions. This positive correlation may be primarily attributed to the provision of raw materials from mining industries used to build instruments of daily use, which allow countries to obtain large amounts of energy as well as infrastructure, boosting economic output. The large magnitude of the standardized coefficients across the various decades considered reflect the importance of the mineral variable relative to other controls. Also on the pragmatic side, international financial institutions such as the World Bank (2003) as well as developing world governments encourage sustainable mining as a means of poverty reduction. They consider the mining sector as a very promising and driving force for economic development under the condition that responsible mining practices are implemented (e.g., close interaction and engagement with the surrounding community, high levels of transparency, responsiveness, and sensitivity to traditional culture, preserving cultural practices, etc.).

In addition, we find some evidence for a significant negative correlation between the presence of tsetse flies and the performance of sub-Saharan Africa's economy (Table C.2, columns 5 and 6). Tsetse flies can hamper economic development in two ways. The first channel through which the tsetse fly can weaken the economy is via the transmission of nagana, a disease affecting livestock. Across regions where tsetse flies had been discovered, it was not possible to generate an agricultural surplus (Nash 1969; Diamond 1997). This, however, was an essential prerequisite for state-building and colonial centralization, which in turn were important drivers of later economic development. Alsan (2015) shows that in particular highly tsetse suitable areas suffer from current low levels of economic development and that the burden of transmitted diseases by the tsetse fly is inter alia responsible for disparate economic outputs across regions. Secondly, by transmitting trypanosomiasis (i.e., sleeping sickness) to humans, tsetse flies may also strongly impair human capital formation since infected children tend to have poor school performance and attendance records. Even if a child is not directly affected by the sleeping sickness but a family member gets sick, the child very likely has to take care of the patient and contribute to the family's income, frequently at the expense of schooling. In the worst-case scenario, sleeping sickness can lead to death (Dargie 2015). In these circumstances, children often have to step into the shoes of the deceased family member and take care of younger siblings or engage in agricultural work, family business, etc., which may result in a permanent school dropout.

The coefficients for population density are significant, at least at the 5 percent level (Table C.2, columns 1 to 4), and show a clear picture of negative correlation with the dependent variable. While findings in the literature are ambiguous, our results are in line with the studies of Mankiw et al. (1992); Kelley and Schmidt (2001), and Klasen and Lawson (2007). One of the main explanations for a negative association between population growth and per capita income can be traced back to capital widening rather than capital deepening, since an increase in population forces an economy to distribute its scarce savings across more individuals, leading to lower per capita income.

To control for the initial stage of a region's development we use the number of "cities" with above 10.000 habitants per administrative region as a proxy. Our results show that the initial stage of economic development matters indeed for current economic outcomes. Unlike Acemoglu et al. (2002) who look at economic development across centuries and find that colonized countries, which were relatively rich during the 15th century are now relatively poor, we do not find evidence for such a reversal of fortune. African regions that were already relatively developed during the early colonial period seem to benefit from better current economic performance.

Moreover, economic output in African regions seems to be, at least to some extent, path-dependent on labor migration. We find that regions, which had an extensive inflow of foreign workers during the colonial period benefit from higher per capita income today, compared to regions where labor migration was not encouraged. It is well documented that an increase in an economy's employment rate almost invariably leads to higher economic output (e.g., Borjas, 1999; Sodipe et al. 2011) and as our results reveal, foreign-born workers may also contribute to an increase in income for the entire population. This positive association between foreign workforce and the economy's output seems to be persistent throughout the decades. A possible explanation for this finding might be that workers who migrated during colonial times engaged heavily in the construction of infrastructure, such as railroads that still show long-term economic benefits today.

The findings of previous studies show that the system of governance also plays a role in economic growth and development (Huntington and Dominguez 1975; Landau 1986; Lee 2003; Shen 2007). We use the polity2 variable from the Polity IV project to account for the regime type and find, conforming to the compatibility view (Sirowy and Inkeles 1990), that African regions moving towards democracy are likely to have a higher per capita income in the long run (columns 5 and 6). Democracies can indeed foster economic growth through various means. For instance, contrary to autocracies, democratic regimes allow for greater predictability and stability, creating an investment-friendly environment. In addition, civil liberties and greater political rights are more likely to promote an efficient allocation of resources in the marketplace and provide motivation for citizens to work and engage in profit-maximizing private activities. What is more, democracies are less prone to engage in military conflicts, and therefore rather lead to better socio-economic outcomes.

Lastly, we account for the potential influence of life expectancy at birth on economic performance. We thereby consider only the latest two birth cohorts due to a lack of data availability for earlier decades. It has been widely debated whether the improvement of life expectancy contributes to the economic growth of a country, however, results from previous studies are not conclusive. Like Bloom et al. (2004); Well (2007); Aghion et al. (2010) and Bloom et al. (2014), we find a positive correlation, indicating that territories with greater longevity do benefit from higher per capita GDP levels. One of the key mechanisms behind this positive association is that improved life expectancy tends to increase education and decrease life-time labor supply if it is elastic enough. More precisely, an increase in life expectancy means, besides improved longevity, that the active and healthy part of life (ALE) increases relative to the inactive (frail) phase, causing an income and substitution effect (Strulik and Werner 2012). If the latter exceeds the former, which happens when the labor supply is elastic enough, there will be a decrease in the aggregated labor supply of middle-aged individuals. A simultaneous increase in education and a drop in the labor supply as a result of higher longevity are not contradictory, but instead, show evidence that increased life expectancy can be an important driver of human capital formation and economic growth.

C.7. Robustness test

Even though nighttime light data have been extensively used in economic studies, typically to measure economic activity, these data are not entirely without shortcomings. One of the main issues that NOAA nighttime light data poses to our study is that nighttime lights in rural areas and in low-density settlements are not easily detectable from space. It is true that nighttime lights measure better economic activity in urban areas, first because of the type of lights required (i.e., high-pressure sodium lamps) in order to be detected by satellites, and second because higher population densities in cities produce more concentrated sources of lights. Since we are unable to account for these conditions and because we want to make sure that our results are robust, we perform a sensitivity analysis where we use real GDP per capita data, collected by Gennaioli et al. (2013). Based on an aggregated database including 1,569 sub-national regions from a total of 110 countries, which are mostly available at the first-level administrative division[37], Gennaioli et al. (2013) construct regional GDP data. Since data on regional GDP are not available for all countries, the authors use data on income (six countries), expenditure (eight countries), wages (three countries), gross value added (two countries), and consumption, investment, and government expenditure (one country). For our robustness test, we hence derive the regional GDP[38] per capita variable from this database. Because regions are aggregated to the highest administrative subdivision and not all our countries studied are available[39], our dataset declines to 626 observations.

Replacing our dependent variable with real GDP per capita, we perform our repeated cross-sectional regression analysis. From Table C.7 we infer that our main variable of interest, the educational gender gap remains significant at a 5 percent level for most birth cohorts, except for individuals born in the 1930s and 1940s. Like with our main regression model, we find that male years of schooling is significantly and positively correlated with economic development when measured with per capita GDP. Our findings with respect to colonizer identity seem to be robust as well. The current economic performance of territories that were colonized by the French appears to be worse compared to today’s economic activity of former British territories.

[37] The first-level administrative division used by Gennaioli et al. (2013) mostly comprises states and provinces.

[38] An overview of the type and source of regional GDP data for the countries included in our sample can be found in the Appendix, Table C.13. Gennaioli et al. (2013) obtain data on regional population from Thomas Brinkhoff: City Population, http://www.citypopulation.de/

[39] 7 countries are missing including Botswana, Ethiopia, Guinea, Liberia, Mali, Rwanda, and Sierra Leone

Moreover, the positive association between per capita economic output and having early access to railways holds. More surprisingly, the mineral variable, which was positively correlated with nighttime light intensity per capita at a 1 percent significance level throughout all decades in our main regression analysis and important in terms of effect size, loses its significance in our robustness analysis. This is very likely due to the use of a subset of our sample excluding some countries in which the mineral sector plays a substantial role like Guinea, Liberia, and Sierra Leone. Moreover, the migration of foreign workers seems to matter very little for economic growth when using actual GDP per capita data as a proxy. Although the regression coefficients are still positive, significance has waned, except for the 1950s birth cohort. Finally, the potential effect of democracy does not provide a clear picture under the GDP per capita proxy. While a move towards democracy is positively associated with current economic performance in sub-Saharan African regions during the 1960s, we find a negative correlation between the polity2 variable and economic development when looking at the 1970s. We also apply real GDP per capita data to test the robustness of the positive association between female education and economic performance. Table C.8 shows positive regression coefficients for female education, significant at a 1 percent level throughout all birth decades, confirming the positive correlation with economic development that we find in our main analysis. Once again, we omit the male years of schooling variable to avoid potential multicollinearity in our regression model. We observe from the results that the coefficients of our control variables behave very similarly, in terms of coefficient signs and significance levels, to the ones from Table C.7 where we use the educational gender gap as a main variable of interest.

C.8. Conclusion

Though there is no doubt that Africa underwent a substantial schooling revolution during the 20^{th} century, it remains not only the least educated but also became the most gender unequal continent in terms of educational provision by the 1980s, showing poor economic performance. While the impact of human capital formation on economic growth has been widely studied, the effects of educational gender disparities have been addressed in a far too limited manner. Knowing that two-third of the world’s countries, which have not achieved gender parity in primary education are located in sub-Saharan Africa (UNESCO 2020), we considered it important to investigate the long-term consequences of long-standing gender gaps in education on current economic outcomes in this part of the world. While we do not claim causality, our results show sufficient evidence for a significant negative relationship between prevailing educational gender inequality in sub-Saharan African regions throughout the 20th century and present-day economic performance, leading us to the conclusion that path dependency matters. We also go beyond analyzing the direct relationship between historical gender disparities and economic development by carrying out a mediation analysis. Our findings show that part of this negative correlation is mediated by fertility. Bearing in mind that better educated women tend to have lower fertility rates, we examine whether sub-Saharan African regions could have benefited economically from an early initial investment into girls' education, and we can answer this question with a clear yes. Again, we do not make causal claims but rather emphasize the strong positive correlation we detect between female education during the past century and current regional GDP per capita output, suggesting that sub-Saharan African regions actually miss out on economic gains when keeping girls' education at low levels. Therefore, it is essential to find and tackle the roots of educational gender gaps. Depending on whether gender gaps are dynamic or structural, the approach to remedy diverges. In the case of dynamic gender gaps, an overall investment in education may be a useful policy implication. Structural gender disparities in schooling, on the other hand, are often at the source of region-specific biases prevailing against female education that need to be tackled. While this study has merely focused on the implications of educational gender inequality and female education on economic performance in African regions, it is essential to point out that working towards gender parity in education should be a priority in itself, independent of economic outcomes. Female education plays an important role in many other development fields, besides the economic sector, notably in social development, and therefore investment into the education of girls may come with many social benefits including the empowerment of women. This may likewise lead to positive spillover effects, not only reducing gender inequality at a household level but also affecting the employment sector, the gender wage gap, and female participation in various spheres including politics, which may be subject to further studies.

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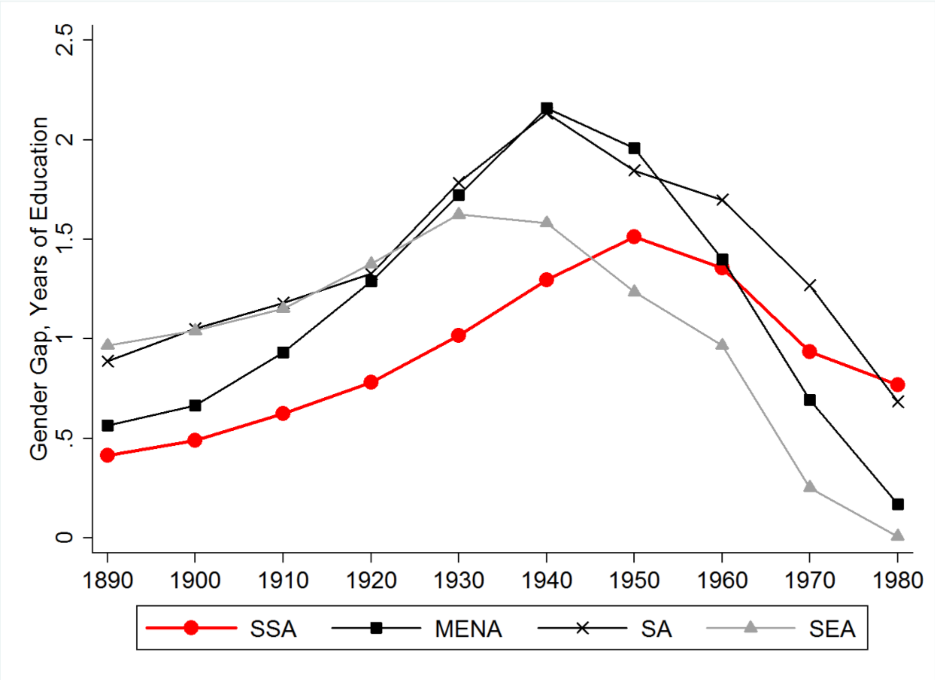
C.10. Figures and tables

C.10.1. Figures

Figure C.1: Educational gender gaps in developing world regions, 1890-1980



Source: Baten, de Haas, Kempter, Meier zu Selhausen (2021)

Figure C.2: Correlation between nighttime light intensity per capita and GDP

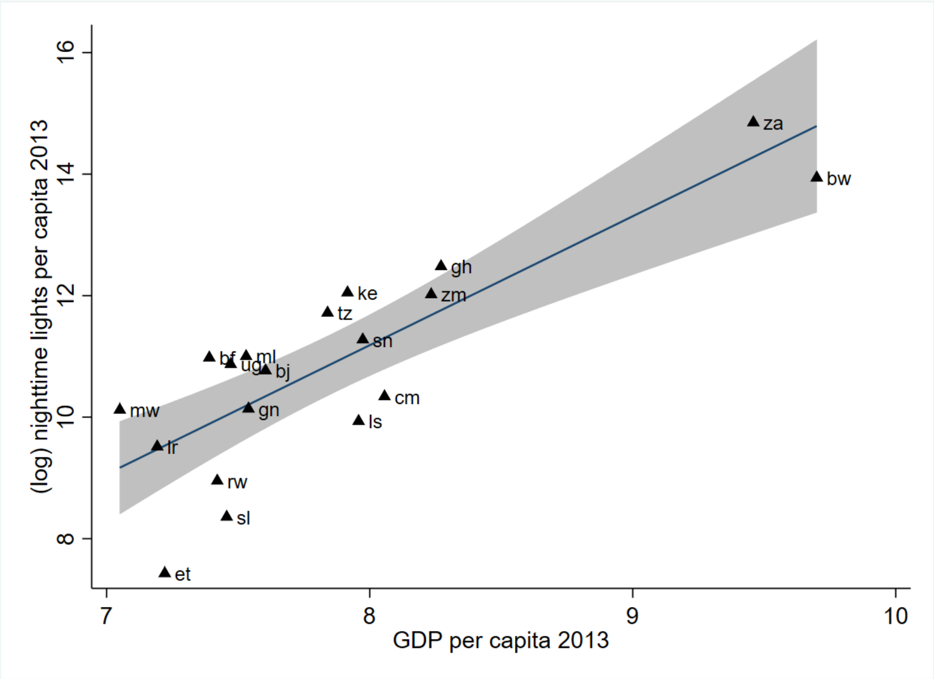


Figure C.3: Correlation between nighttime light intensity per km^2 and GDP

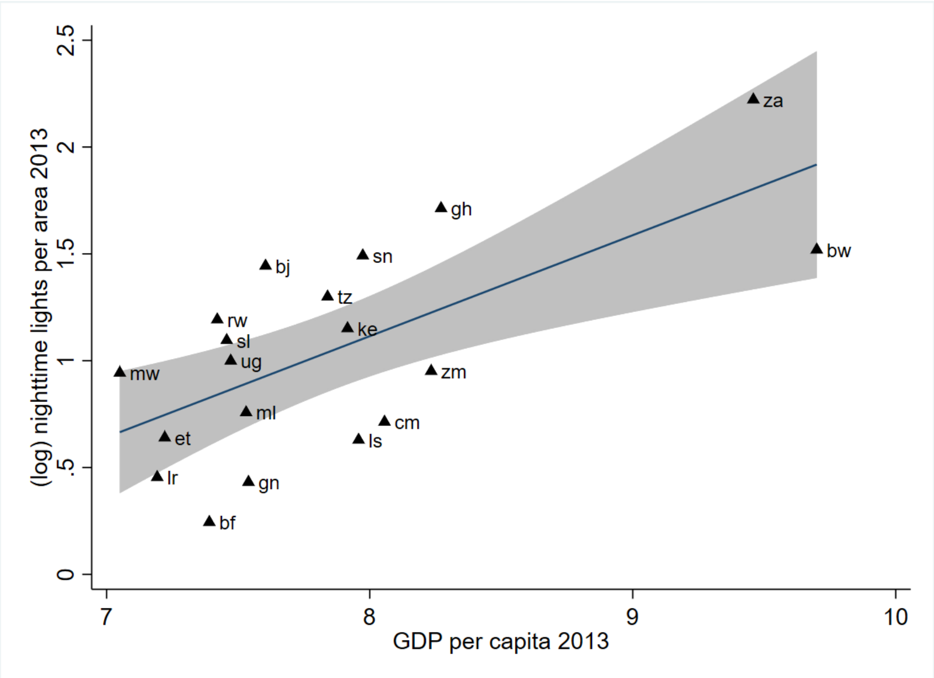


Figure C.4: Distribution of GDP data (2013) at the country level

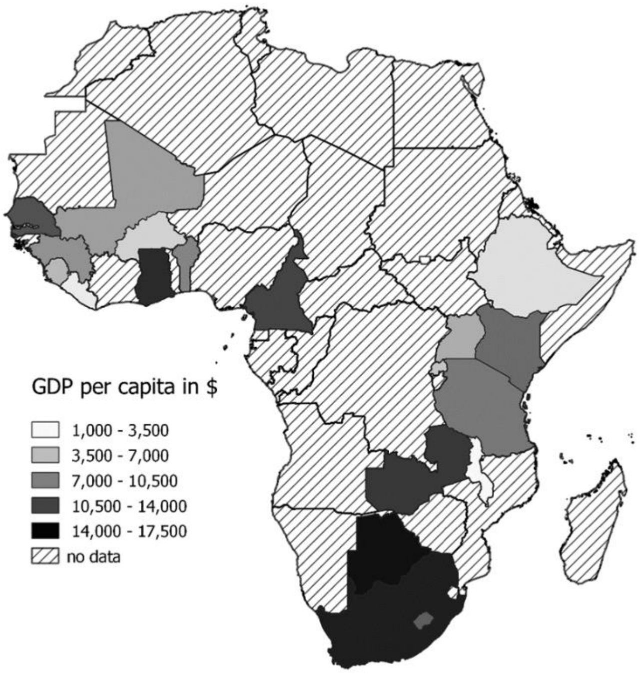


Figure C.5: Distribution of nighttime light data (2013) at the country level

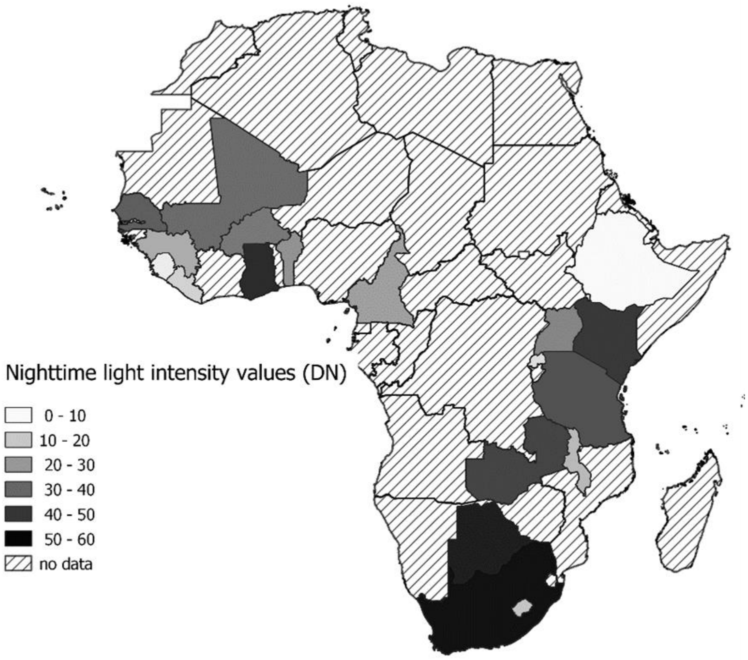


Figure C.6: Distribution of nighttime light data at the sub-national level

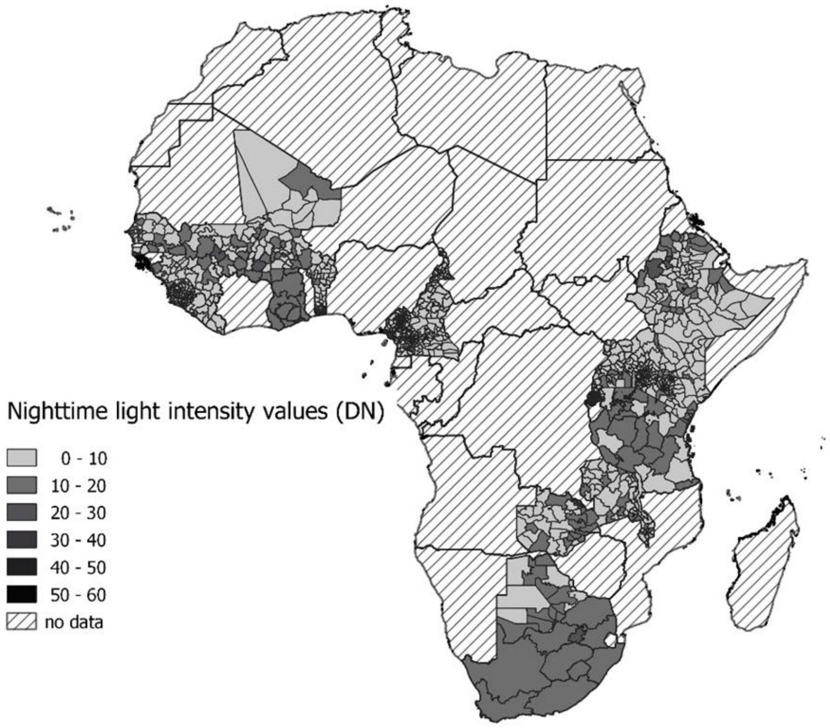
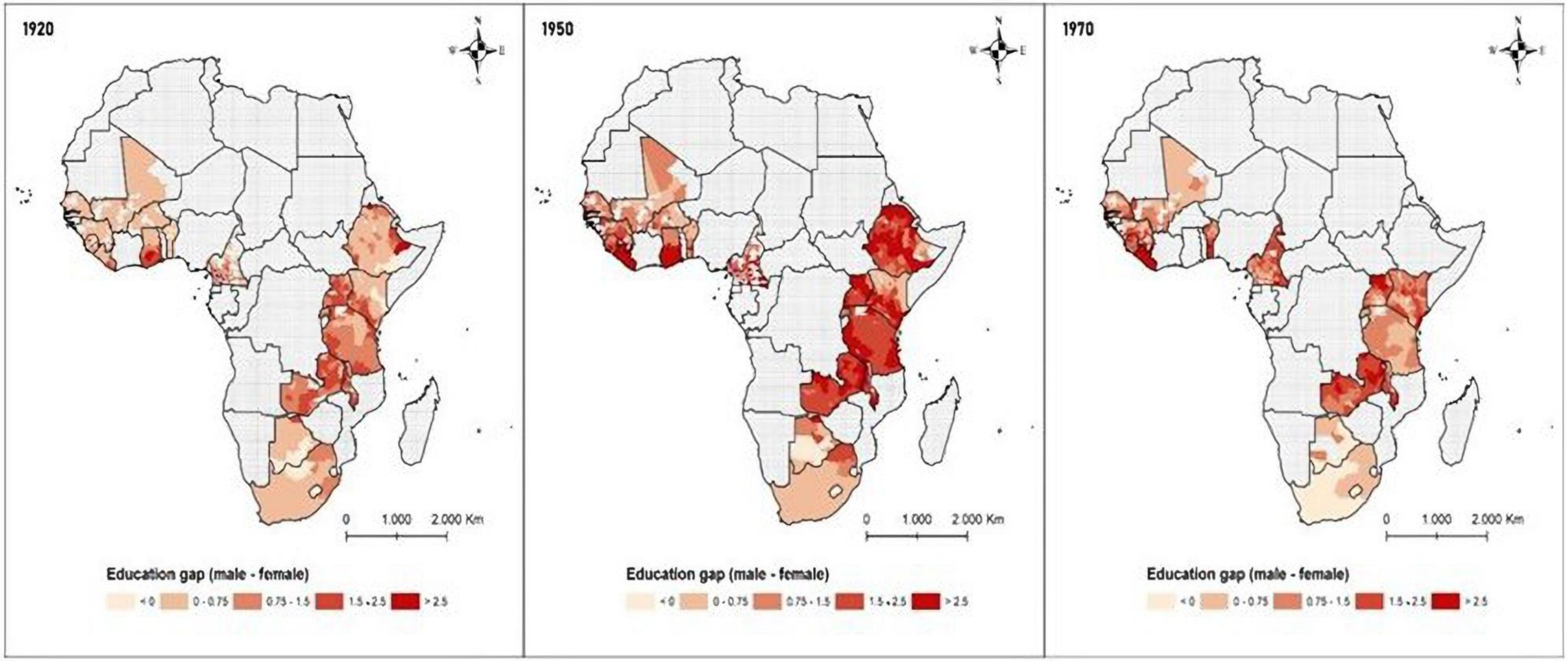


Figure C.7: Educational gender disparities in sub-Saharan African regions during the 20th century



Note: Brighter color = smaller gender gaps. Educational gender gaps controlling for linear and quadratic effects of male years of schooling (educational gender Kuznets curve) for 1920s, 1950s and 1970s. Maps are based on educational gender inequality data used in Baten, de Haas, Kempter, Meier zu Selhausen (2021).

Figure C.8: Correlation between the gender gap in education and nighttime light intensity

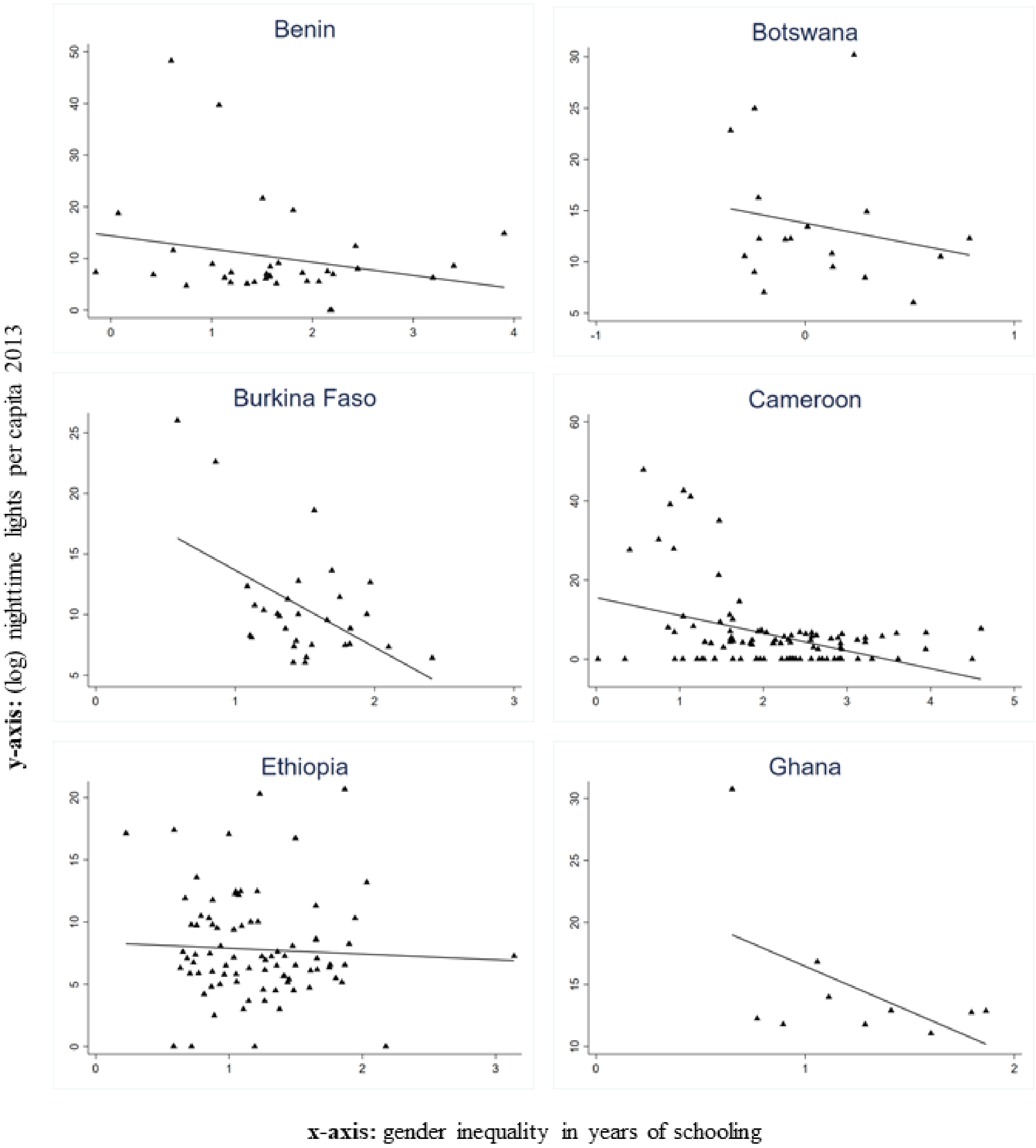


Figure C.8 (cont.): Correlation between the gender gap in education and nighttime light intensity

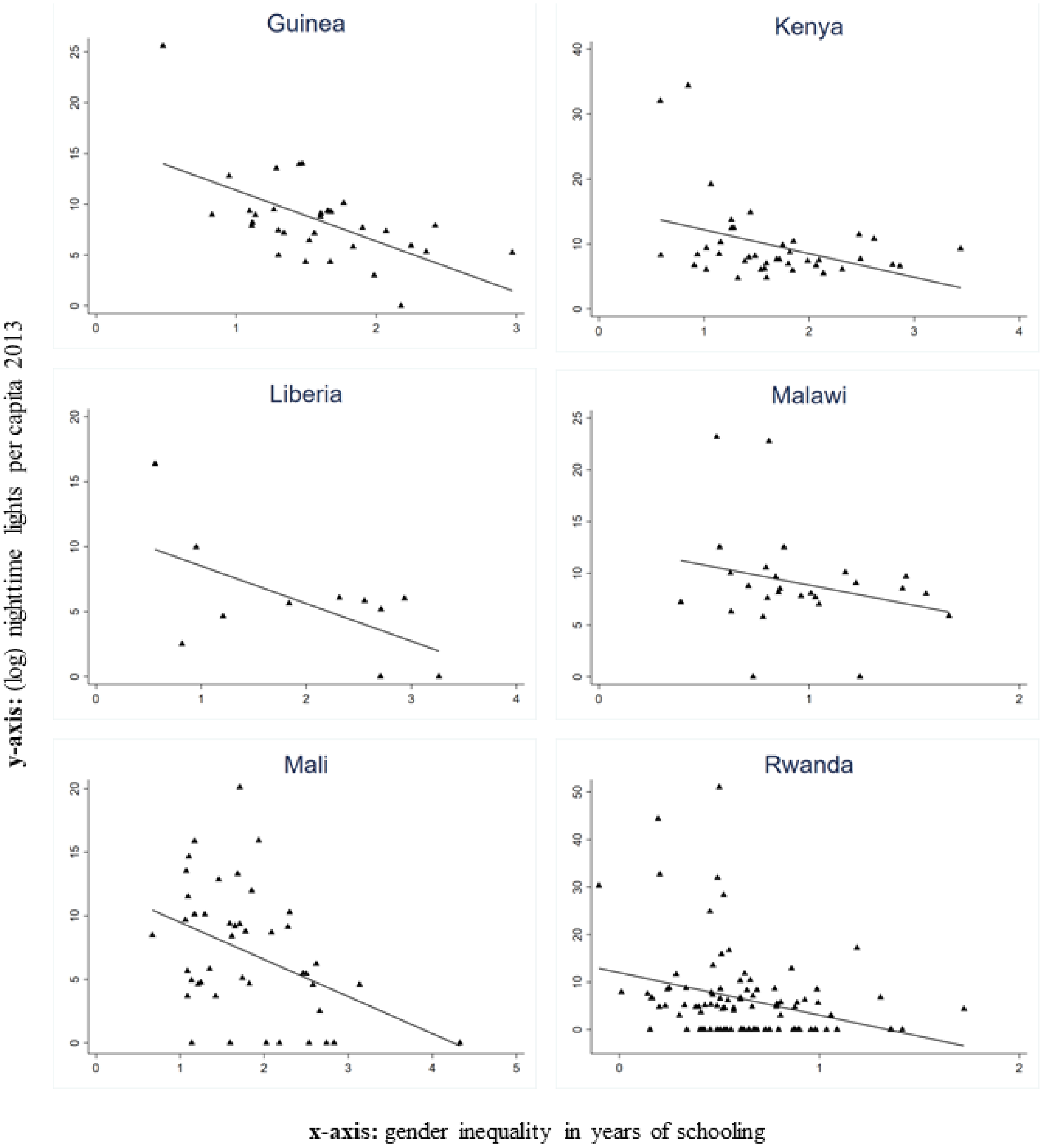


Figure C.8 (cont.): Correlation between the gender gap in education and nighttime light intensity

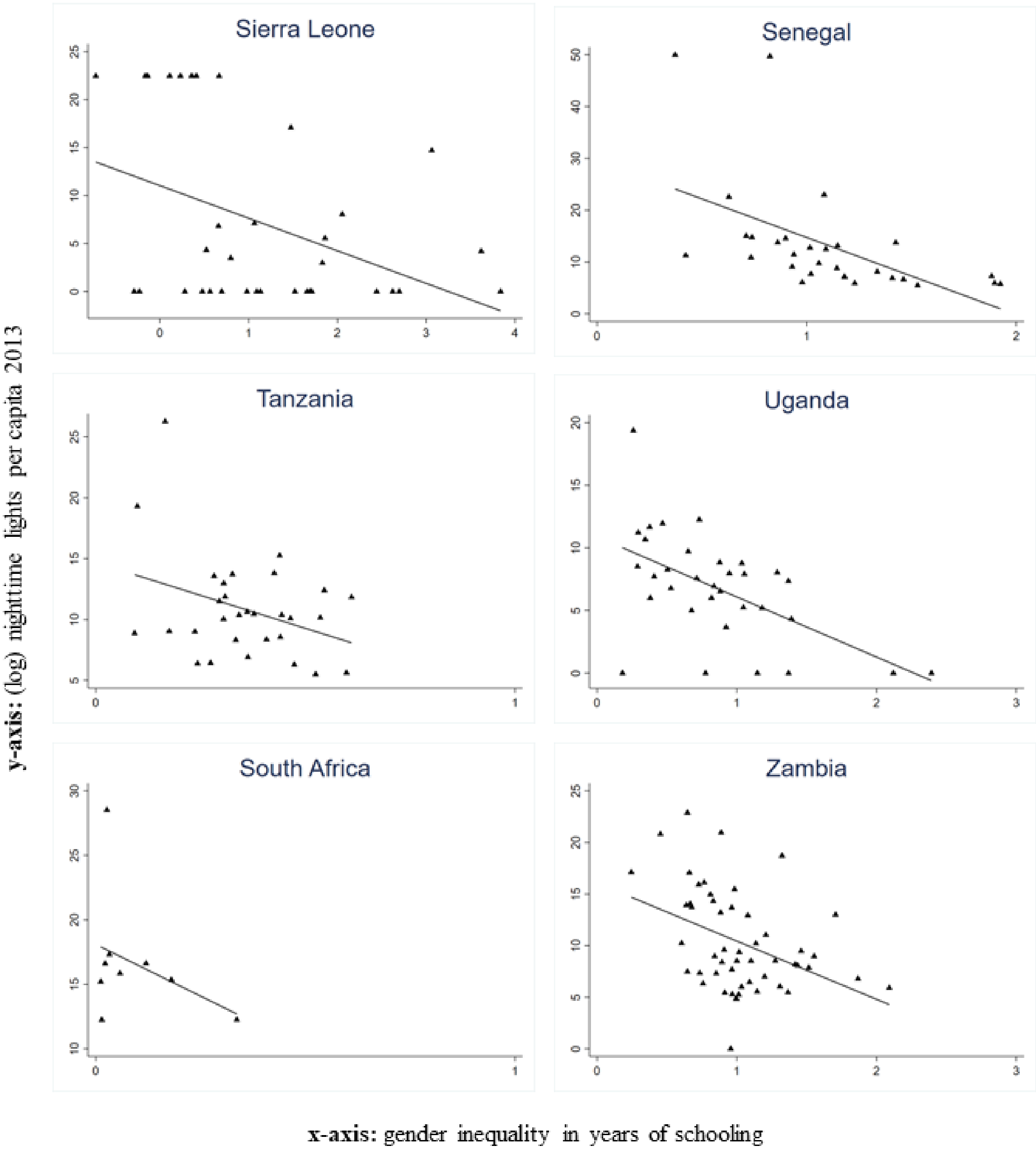


Figure C.9: Correlation between the female education and nighttime light intensity

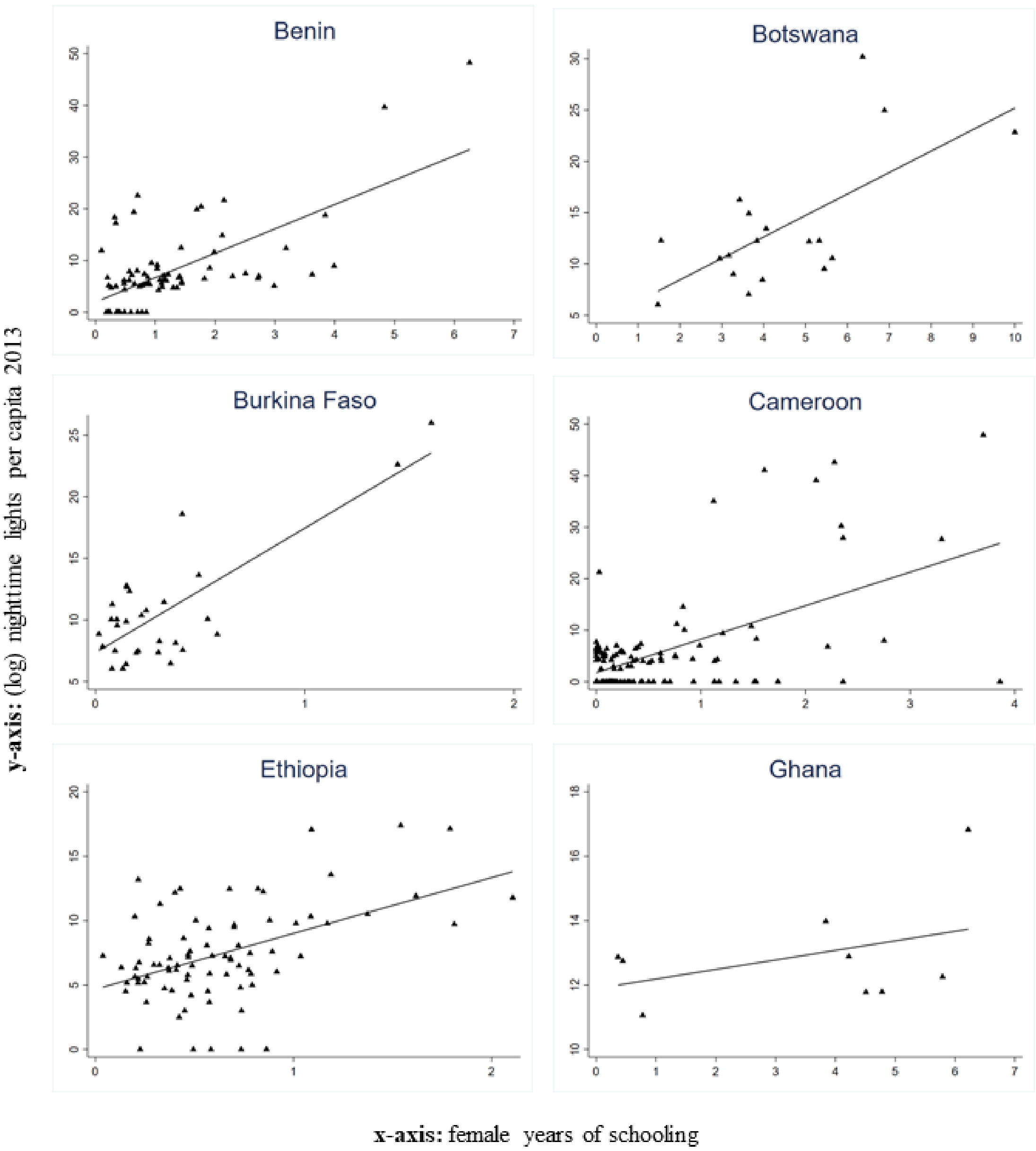


Figure C.9 (cont.): Correlation between the female education and nighttime light intensity

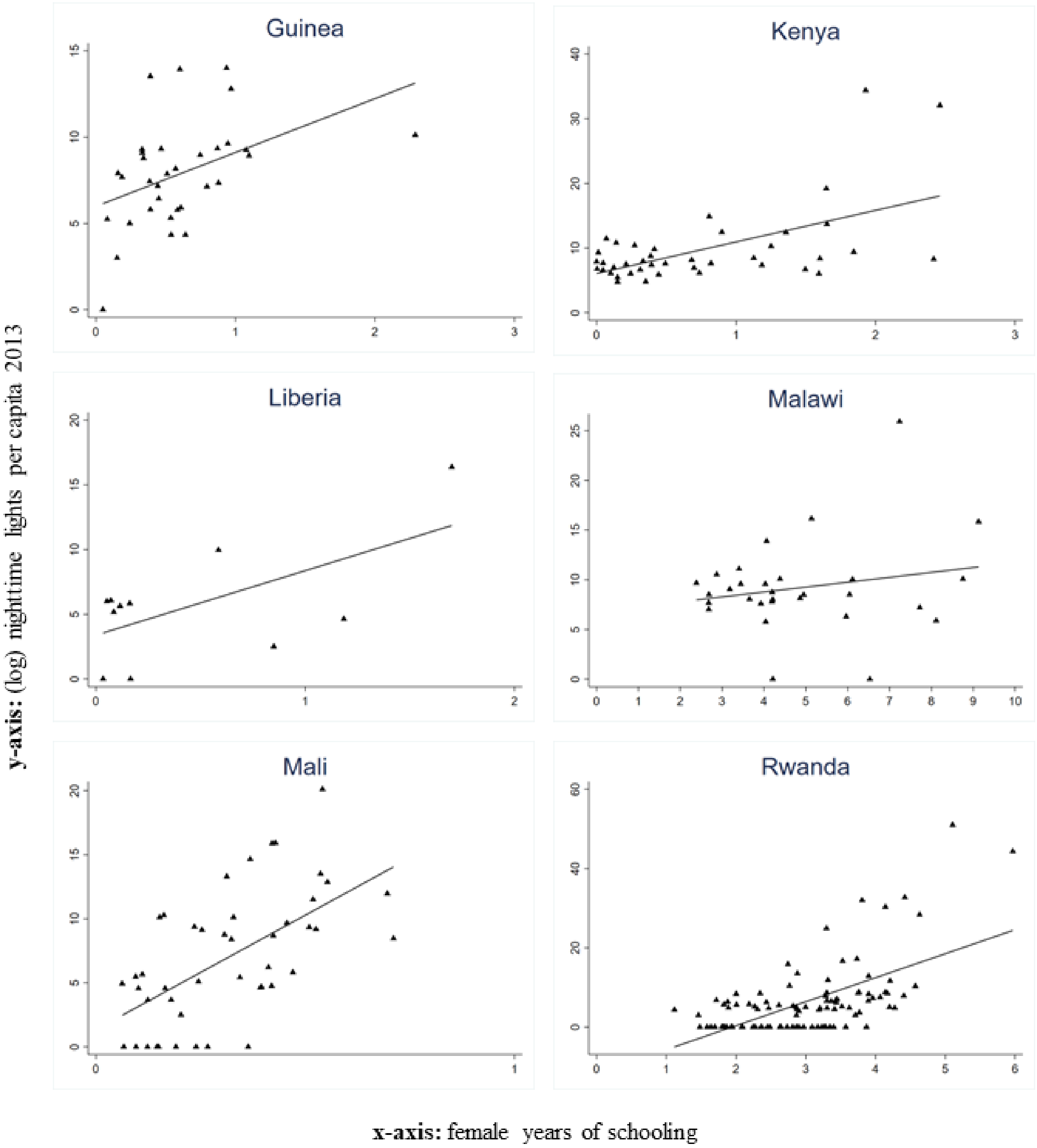


Figure C.9 (cont.): Correlation between the female education and nighttime light intensity

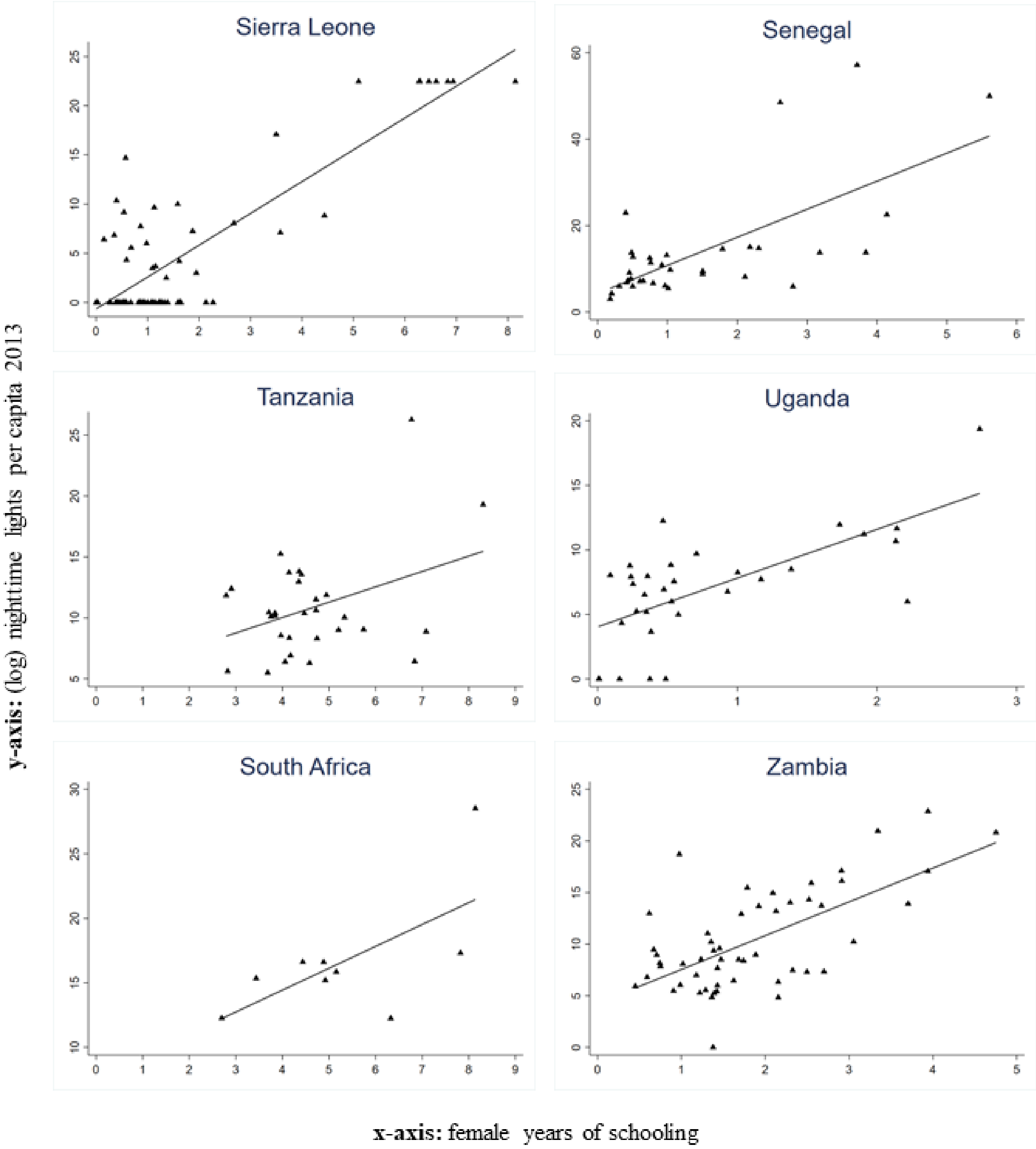
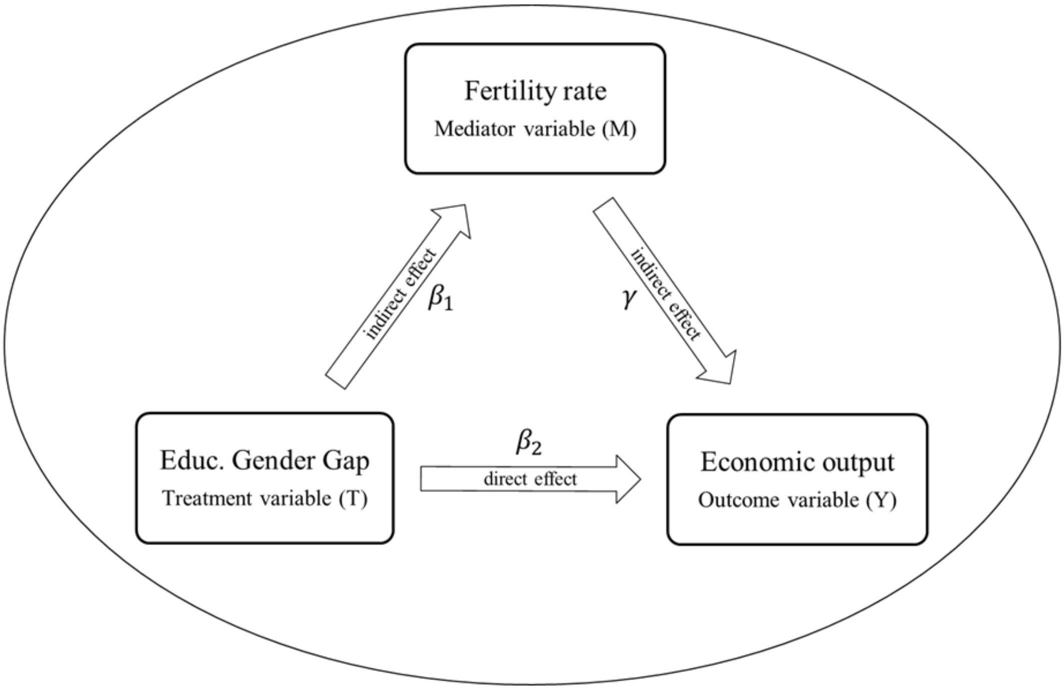


Figure C.10: Mediation model



C.10.2. Tables

Table C.1: Descriptive statistics of variables

	1920-1929					1930-1939					1940-1949				
Variables	Obs.	Mean	SD	Min	Max	Obs.	Mean	SD	Min	Max	Obs.	Mean	SD	Min	Max
Nighttime lights p.c. (log)	803	8.067	7.580	0.000	51.000	804	8.078	7.582	0.000	51.000	805	8.096	7.595	0.000	51.000
Educational gender gap	803	0.895	0.949	-3.600	6.500	804	1.367	1.112	-1.993	6.417	805	1.824	1.241	-1.525	5.368
Female years of education	803	0.367	0.908	0.000	8.250	804	0.553	0.910	0.000	7.534	805	1.079	1.317	0.000	8.141
Male years of education	803	1.262	1.407	0.000	11.000	804	1.921	1.636	0.000	9.105	805	2.903	2.127	0.051	9.333
Dummy if coast	803	0.096	0.294	0.000	1.000	804	0.096	0.294	0.000	1.000	805	0.096	0.294	0.000	1.000
French colonies	803	0.306	0.461	0.000	1.000	804	0.307	0.462	0.000	1.000	805	0.308	0.462	0.000	1.000
British colonies	803	0.267	0.442	0.000	1.000	804	0.266	0.442	0.000	1.000	805	0.266	0.442	0.000	1.000
Mandated territories	803	0.296	0.457	0.000	1.000	804	0.296	0.457	0.000	1.000	805	0.296	0.457	0.000	1.000
Independent countries	803	0.131	0.337	0.000	1.000	804	0.131	0.337	0.000	1.000	805	0.130	0.337	0.000	1.000
Cash crops p.c. (log)	782	0.571	1.237	0.000	5.945	783	0.528	1.051	0.000	4.900	784	0.593	1.090	0.000	4.532
Minerals p.c. (log)	803	0.029	0.326	0.000	4.866	804	0.053	0.567	0.000	7.877	805	0.051	0.547	0.000	7.299
Dummy if railroad	803	0.167	0.373	0.000	1.000	804	0.210	0.408	0.000	1.000	805	0.245	0.430	0.000	1.000
Dummy if main mission 1924	803	0.248	0.432	0.000	1.000	804	0.248	0.432	0.000	1.000	805	0.247	0.431	0.000	1.000
Tsetse suitability index	736	-0.011	0.648	-1.587	1.495	737	-0.012	0.648	-1.587	1.495	737	-0.012	0.648	-1.587	1.495
Population density (log)	803	0.098	1.582	-5.579	4.781	804	0.660	1.590	-4.747	5.113	805	0.985	1.599	-4.763	5.462
Cities 1920	803	0.133	0.495	0.000	6.000	804	0.133	.495	0.000	6.000	805	0.133	0.495	0.000	6.000
Migration of workers (no)	803	0.573	0.495	0.000	1.000	804	0.573	0.495	0.000	1.000	805	0.574	0.495	0.000	1.000
Migration of workers (little)	803	0.133	0.340	0.000	1.000	804	0.133	0.340	0.000	1.000	805	0.133	0.340	0.000	1.000
Migration of workers (extensive)	803	0.294	0.456	0.000	1.000	804	0.294	0.456	0.000	1.000	805	0.293	0.455	0.000	1.000

Table C.1 (cont.): Descriptive statistics of variables

	1950-1959					1960-1969					1970-1979				
Variables	Obs.	Mean	SD	Min	Max	Obs.	Mean	SD	Min	Max	Obs.	Mean	SD	Min	Max
Nighttime lights p.c. (log)	752	8.042	7.698	0.000	51.000	1,092	6.898	7.982	0.000	57.158	1,062	6.795	8.033	0.000	57.158
Educational gender gap	752	1.818	1.081	-3.000	6.107	1,092	1.664	1.022	-2.100	5.245	1,062	1.303	0.947	-1.814	5.394
Female years of education	752	1.978	1.888	0.000	10.000	1,092	3.670	2.658	0.016	10.882	1,062	4.533	2.976	0.082	11.720
Male years of education	752	3.796	2.288	0.073	10.000	1,092	5.335	2.775	0.101	11.338	1,062	5.836	2.715	0.252	11.828
Dummy if coast	752	0.085	0.279	0.000	1.000	1,092	0.079	0.269	0.000	1.000	1,062	0.081	0.273	0.000	1.000
French colonies	752	0.275	0.447	0.000	1.000	1,092	0.375	0.484	0.000	1.000	1,062	0.386	0.487	0.000	1.000
British colonies	752	0.285	0.452	0.000	1.000	1,092	0.202	0.402	0.000	1.000	1,062	0.180	0.384	0.000	1.000
Mandated territories	752	0.315	0.465	0.000	1.000	1,092	0.400	0.490	0.000	1.000	1,062	0.411	0.492	0.000	1.000
Independent countries	752	0.125	0.331	0.000	1.000	1,092	0.022	0.147	0.000	1.000	1,062	0.023	0.149	0.000	1.000
Cash crops p.c. (log)	742	0.714	1.348	0.000	6.594	1,082	1.141	1.945	0.000	8.109	1,052	1.449	2.377	0.000	9.295
Minerals p.c. (log)	752	0.008	0.074	0.000	1.176	1,092	0.004	0.048	0.000	0.995	1,062	0.003	0.027	0.000	0.550
Dummy if railroad	752	0.235	0.425	0.000	1.000	1,092	0.232	0.422	0.000	1.000	1,062	0.237	0.426	0.000	1.000
Dummy if main mission 1924	752	0.227	0.419	0.000	1.000	1,092	0.222	0.416	0.000	1.000	1,062	0.228	0.420	0.000	1.000
Tsetse suitability index	687	-1.001	0.663	-1.587	1.495	994	0.070	0.684	-2.136	1.495	964	0.077	0.693	-2.136	1.495
Population density (log)	752	1.133	1.681	-4.169	6.504	1,092	1.703	1.704	-5.635	6.921	1,062	2.121	1.710	-5.443	7.309
Cities 1920	752	0.133	0.501	0.000	6.000	985	0.139	0.520	0.000	6.000	955	0.139	0.527	0.000	6.000
Migration of workers (no)	752	0.614	0.487	0.000	1.000	1,092	0.365	0.482	0.000	1.000					
Migration of workers (little)	752	0.128	0.334	0.000	1.000	1,092	0.112	0.315	0.000	1.000					
Migration of workers (extensive)	752	0.258	0.438	0.000	1.000	1,092	0.523	0.500	0.000	1.000					
Polity2						1,092	-1.936	3.465	-9.000	6.000	1,062	-6.681	2.204	-9.000	6.000
Polity2 sq.						1,092	15.745	22.175	0.160	81.000	1,062	49.495	13.664	11.560	81.000
Magnitude of civil war						1,092	0.248	0.517	0.000	1.800	1,062	0.212	0.894	0.000	4.000
Life expectancy at birth						1,092	3.690	0.095	3.453	3.895	1,062	3.793	0.103	3.537	3.973

Table C.2: Educational gender gap and other correlates of regional GDP per capita, measured by nighttime light intensity per capita 2013

Dependent variable:	Nighttime lights p.c. (log)			Nighttime lights p.c. (log)		
	1920-1929	1930-1939	1940-1949	1950-1959	1960-1969	1970-1979
	(1)	(2)	(3)	(4)	(5)	(6)
Educational gender gap	-0.089***	-0.098***	-0.067***	-0.060***	-0.030**	-0.029**
	(0.026)	(0.020)	(0.015)	(0.012)	(0.012)	(0.013)
Male years of education	0.088***	0.072***	0.042***	0.035***	0.034***	0.031***
	(0.022)	(0.016)	(0.010)	(0.008)	(0.007)	(0.007)
Dummy if coast	0.086**	0.097***	0.098***	0.107***	0.092***	0.083**
	(0.035)	(0.035)	(0.035)	(0.041)	(0.035)	(0.036)
French colonies	-0.142***	-0.114***	-0.109***	-0.126***	-0.268***	-0.143**
	(0.033)	(0.034)	(0.034)	(0.036)	(0.057)	(0.064)
Mandated territories	-0.027	0.037	0.017	-0.001	0.108	-0.149
	(0.061)	(0.063)	(0.062)	(0.073)	(0.074)	(0.110)
Independent countries	-0.094	-0.055	-0.060	-0.027	-0.393***	-0.260***
	(0.064)	(0.065)	(0.064)	(0.076)	(0.088)	(0.086)
Cash crop p.c. (log)	-0.001	-0.005	-0.009	-0.009	-0.002	-0.002
	(0.007)	(0.008)	(0.008)	(0.007)	(0.005)	(0.004)
Minerals p.c. (log)	0.309***	0.230***	0.238***	1.469***	1.817***	3.320***
	(0.023)	(0.014)	(0.015)	(0.119)	(0.148)	(0.271)
Dummy if railroad	0.080***	0.085***	0.104***	0.114***	0.091***	0.091***
	(0.023)	(0.022)	(0.021)	(0.024)	(0.023)	(0.024)
Dummy if main mission 1924	-0.016	-0.018	-0.021	-0.039	-0.002	0.009
	(0.024)	(0.024)	(0.024)	(0.027)	(0.026)	(0.026)
Tsetse suitability index	0.002	0.002	-0.006	-0.026	-0.067***	-0.058***
	(0.018)	(0.019)	(0.019)	(0.021)	(0.022)	(0.022)
Population density (log)	-0.023***	-0.025***	-0.023***	-0.016**	-0.006	-0.0110
	(0.006)	(0.006)	(0.006)	(0.007)	(0.007)	(0.007)
Cities 1920	0.096***	0.094***	0.087***	0.099***	0.059**	0.064**
	(0.023)	(0.024)	(0.023)	(0.026)	(0.027)	(0.028)
Immigration of workers (little)	-0.042	-0.043	-0.049*	-0.036		
	(0.026)	(0.027)	(0.027)	(0.029)		
Immigration of workers (extensive)	0.091**	0.109**	0.090**	0.106**		
	(0.042)	(0.043)	(0.042)	(0.045)		
Polity2					0.081***	0.080***
					(0.010)	(0.012)
Polity2 sq.					0.011***	0.004***
					(0.001)	(0.002)
Magnitude of civil war					-0.057	-0.011
					(0.037)	(0.018)
Life expectancy at birth (log)					2.196***	0.288
					(0.263)	(0.258)
Constant	-0.020	-0.060	-0.034	-0.100	-8.259***	-0.687
	(0.099)	(0.101)	(0.100)	(0.114)	(0.995)	(1.124)
Rho	1.077***	0.801***	1.180*	1.061	1.143	1.317
	(0.215)	(0.280)	(0.656)	(4.037)	(4.040)	(6.395)
Observations	716	717	717	678	985	955
R-squared	0.386	0.490	0.498	0.453	0.513	0.494
Region FE	Yes	Yes	Yes	Yes	Yes	Yes

Note: Repeated cross-sectional regressions, 6 decades respectively using the SAR model. Regression models are corrected for spatial autocorrelation. Rho indicates the spatial autocorrelation coefficient. Dependent variable: (log) nighttime lights per capita (multiplied by 100 for readability); Main independent variable: educational gender gap; Reference categories: British colonies, no immigration of workers; Robust standard errors (in parentheses) and regional fixed effects. Significance codes: *** p<0.01, ** p<0.05, * p<0.1. See Appendix for data construction and sources.

Table C.3: Educational gender gap and other correlates of regional GDP per capita, std. coef

Dependent variable:	Nighttime lights p.c. (log)			Nighttime lights p.c. (log)		
	1920-1929	1930-1939	1940-1949	1950-1959	1960-1969	1970-1979
	(1)	(2)	(3)	(4)	(5)	(6)
Educational gender gap	-0,084	-0,084	-0,083	-0.065	-0.031	-0,027
Male years of education	0.124	0.118	0.089	0.080	0.094	0.084
Dummy if coast	0.025	0.029	0.029	0.030	0.025	0.025
French colonies	-0.065	-0.053	-0.050	-0.056	-0.130	-0.070
Mandated territories	-0.017	0.011	0.008	-0.0004	0.050	0.073
Independent countries	0,032	-0.019	-0.020	-0.009	-0.058	-0.039
Cash crop p.c. (log)	-0,001	-0,006	-0,003	-0,003	-0,0002	-0,002
Minerals p.c. (log)	0,101	0,130	0,130	0,109	0,087	0,090
Dummy if railroad	0,013	0,035	0,044	0,061	0,038	0,039
Dummy if main mission 1924	-0,007	-0,008	-0,009	-0,016	-0,001	0,004
Tsetse suitability index	0,001	0,001	-0,004	-0,017	-0,046	-0,025
Population density (log)	-0,036	-0,040	-0,037	-0,027	-0,010	-0,019
Cities 1920	0.048	0.047	0.043	0.050	0.042	0.039
Immigration of workers (little)	-0,014	-0,015	-0,017	-0,012		
Immigration of workers (extensive)	0,041	0,050	0,050	0,041		
Polity2					0,281	0,176
Polity2 sq.					0,244	0,055
Magnitude of civil war					-0,029	0,010
Life expectancy at birth (log)					0,209	0,030
Observations	716	717	717	678	985	955
Region FE	Yes	Yes	Yes	Yes	Yes	Yes

Note: Standardized coefficients from Table C.2.

Table C.4: Mediated fertility effects

Dependent variable:	Nighttime lights p.c. (log)	Nighttime lights p.c. (log)
	1960-1969	1970-1979
	(1)	(2)
Educational gender gap	-0.165***	-0.162***
	(0.024)	(0.026)
Fertility rates (log)	-0.048*	-0.215***
	(0.029)	(0.037)
Constant	0.817***	1.944***
	(0.206)	(0.270)
Observations	1,092	1,062
R-squared	0.044	0.054
ACME	0.003	0.026
Direct effect	-0.165	-0.162
Total effect	-0.162	-0.136
% Total effect mediated	-0.019	-0.189

Note: Causal Mediation Analysis (Hicks and Tingley, 2011). Treatment variable: educational gender gap; Outcome variable: nighttime lights per capita (log); Mediator variable: fertility rates (log) Significance codes: *** p<0.01, ** p<0.05, * p<0.1.

Table C.5: Female education and other correlates of regional GDP per capita, measured by nighttime light intensity per capita 2013

Dependent variable:	Nighttime lights p.c. (log)			Nighttime lights p.c. (log)		
	1920-1929	1930-1939	1940-1949	1950-1959	1960-1969	1970-1979
	(1)	(2)	(3)	(4)	(5)	(6)
Female years of education	0.088***	0.066***	0.036***	0.037***	0.034***	0.031***
	(0.022)	(0.016)	(0.010)	(0.008)	(0.007)	(0.007)
Dummy if coast	0.086**	0.096***	0.094***	0.096**	0.094***	0.084**
	(0.035)	(0.036)	(0.035)	(0.041)	(0.035)	(0.036)
French colonies	-0.142***	-0.132***	-0.131***	-0.144***	-0.267***	-0.140**
	(0.033)	(0.033)	(0.033)	(0.036)	(0.057)	(0.062)
Mandated territories	-0.027	0.009	-0.001	-0.005	0.106	-0.146
	(0.061)	(0.062)	(0.061)	(0.073)	(0.074)	(0.110)
Independent countries	-0.094	-0.077	-0.083	-0.060	-0.382***	-0.259***
	(0.064)	(0.065)	(0.064)	(0.075)	(0.083)	(0.086)
Cash crop p.c. (log)	-0.001	-0.005	-0.010	-0.008	-0.002	-0.002
	(0.007)	(0.008)	(0.008)	(0.007)	(0.005)	(0.004)
Minerals p.c. (log)	0.309***	0.228***	0.235***	1.451***	1.816***	3.319***
	(0.023)	(0.014)	(0.015)	(0.119)	(0.148)	(0.271)
Dummy if railroad	0.080***	0.078***	0.100***	0.111***	0.091***	0.091***
	(0.023)	(0.022)	(0.021)	(0.024)	(0.023)	(0.024)
Dummy if main mission 1924	-0.017	-0.022	-0.025	-0.042	-0.003	0.009
	(0.024)	(0.024)	(0.024)	(0.027)	(0.026)	(0.026)
Tsetse suitability index	0.002	-0.005	-0.013	-0.036*	-0.065***	-0.0569***
	(0.018)	(0.018)	(0.018)	(0.020)	(0.022)	(0.021)
Population density (log)	-0.023***	-0.026***	-0.025***	-0.017**	-0.005	-0.011
	(0.006)	(0.006)	(0.006)	(0.007)	(0.007)	(0.007)
Cities 1920	0.095***	0.089***	0.084***	0.094***	0.060**	0.063**
	(0.023)	(0.024)	(0.024)	(0.026)	(0.027)	(0.028)
Immigration of workers (little)	-0.043	-0.046*	-0.050*	-0.039		
	(0.026)	(0.027)	(0.027)	(0.029)		
Immigration of workers (extensive)	0.091**	0.093**	0.077*	0.094**		
	(0.042)	(0.043)	(0.042)	(0.045)		
Polity2					0.081***	0.080***
					(0.010)	(0.011)
Polity2 sq.					0.011***	0.004***
					(0.001)	(0.002)
Magnitude of civil war					-0.060*	-0.011
					(0.036)	(0.018)
Life expectancy at birth (log)					2.195***	0.304
					(0.263)	(0.240)
Constant	-0.020	-0.062	-0.057	-0.142	-8.243***	-0.751
	(0.099)	(0.101)	(0.100)	(0.113)	(0.995)	(1.062)
Rho	1.078***	1.178**	1.133	1.055	1.150	1.378
	(0.216)	(0.464)	(1.395)	(6.277)	(3.700)	(5.759)
Observations	716	717	717	678	985	955
R-squared	0.386	0.486	0.495	0.449	0.512	0.494
Region FE	Yes	Yes	Yes	Yes	Yes	Yes

Note: Repeated cross-sectional regressions, 6 decades respectively using the SAR model. Regression models are corrected for spatial autocorrelation. Rho indicates the spatial autocorrelation coefficient. Dependent variable: (log) nighttime lights per capita (multiplied by 100 for readability); Main independent variable: female years of education; Reference categories: British colonies, no immigration of workers; Robust standard errors (in parentheses) and regional fixed effects. Significance codes: *** p<0.01, ** p<0.05, * p<0.1. See Appendix for data construction and sources.

Table C.6: Female education and other correlates of regional GDP per capita, std. coef

Dependent variable:	Nighttime lights p.c. (log)			Nighttime lights p.c. (log)		
	1920-1929	1930-1939	1940-1949	1950-1959	1960-1969	1970-1979
	(1)	(2)	(3)	(4)	(5)	(6)
Female years of education	0.080	0.060	0.047	0.070	0.090	0.092
Dummy if coast	0,025	0.028	0.028	0.027	0.025	0.023
French colonies	-0.065	-0.061	-0.061	-0.064	-0.129	-0.068
Mandated territories	-0.012	0.004	0.0004	0.002	0.052	0.072
Independent countries	-0.032	-0.026	-0.028	-0.020	-0.056	-0.039
Cash crop p.c. (log)	-0.001	-0.005	-0.011	-0.011	-0.004	-0.005
Minerals p.c. (log)	0.101	0.129	0.129	0.107	0.087	0.090
Dummy if railroad	0.030	0.032	0.043	0.047	0.038	0.039
Dummy if main mission 1924	-0.007	-0.010	-0.010	-0.018	-0.001	0.004
Tsetse suitability index	0.001	-0.003	-0.008	-0.024	-0.044	-0.040
Population density (log)	-0.036	-0.041	-0.040	-0.029	0.009	-0.019
Cities 1920	0.047	0.044	0.042	0.047	0.031	0.033
Immigration of workers (little)	-0.015	-0.016	-0.017	-0.013		
Immigration of workers (extensive)	0.041	0.042	0.035	0.041		
Polity2					0.281	0.176
Polity2 sq.					0.244	0.055
Magnitude of civil war					-0.031	0.010
Life expectancy at birth (log)					0.209	0.031
Observations	716	717	717	678	985	955
Region FE	Yes	Yes	Yes	Yes	Yes	Yes

Note: Standardized coefficients from Table C.5

Table C.7: Educational gender gap and other correlates of real GDP per capita

Dependent variable:	Real GDP p.c. (log)			Real GDP p.c. (log)		
	1920-1929	1930-1939	1940-1949	1950-1959	1960-1969	1970-1979
	(1)	(2)	(3)	(4)	(5)	(6)
Educational gender gap	-0.530**	-0.256	-0.138	-0.136**	-0.175**	-0.154**
	(0.245)	(0.155)	(0.104)	(0.058)	(0.068)	(0.063)
Male years of education	0.540***	0.299***	0.160***	0.120***	0.125***	0.113***
	(0.176)	(0.093)	(0.047)	(0.030)	(0.040)	(0.040)
Dummy if coast	-0.023	-0.018	0.013	0.164	0.219	0.147
	(0.225)	(0.269)	(0.280)	(0.154)	(0.197)	(0.225)
French colonies	-0.698***	-0.888***	-0.862***	-0.842***	-7.036*	-0.209
	(0.258)	(0.244)	(0.247)	(0.143)	(4.102)	(0.379)
Mandated territories	0.350	0.145	0.149	0.155	-1.020	0.734**
	(0.229)	(0.209)	(0.225)	(0.116)	(0.728)	(0.343)
Independent countries	-	-	-	-	-	-
Cash crop p.c. (log)	-0.039	-0.086	-0.109	-0.070	-0.037	-0.045
	(0.063)	(0.085)	(0.095)	(0.042)	(0.039)	(0.039)
Minerals p.c. (log)	0.035	0.006	-0.004	-0.111	-0.392	-1.085
	(0.062)	(0.040)	(0.043)	(0.351)	(0.714)	(1.417)
Dummy if railroad	0.388***	0.218	0.271*	0.189**	0.293***	0.448***
	(0.144)	(0.156)	(0.136)	(0.090)	(0.102)	(0.145)
Dummy if main mission 1924	0.334	0.379	0.411	0.053	0.139	0.147
	(0.271)	(0.324)	(0.324)	(0.243)	(0.251)	(0.274)
Tsetse suitability index	-0.039	-0.029	-0.022	0.037	-0.021	-0.057
	(0.102)	(0.097)	(0.107)	(0.087)	(0.130)	(0.142)
Population density (log)	0.013	0.019	0.029	-0.0003	-0.019	-0.032
	(0.037)	(0.038)	(0.039)	(0.025)	(0.036)	(0.042)
Immigration of workers (little)	-0.591**	-0.569**	-0.596***	-0.317		
	(0.229)	(0.221)	(0.204)	(0.214)		
Immigration of workers (extensive)	0.212	0.306	0.278	0.273**		
	(0.206)	(0.202)	(0.216)	(0.106)		
Polity2					0.853*	-0.716*
					(0.486)	(0.392)
Polity2 sq.					0.163	-0.068*
					(0.099)	(0.036)
Magnitude of civil war					2.759	0.059
					(1.925)	(0.059)
Life expectancy at birth (log)					41.45	-2.228
					(26.68)	(2.324)
Constant	6.832***	6.836***	6.791***	6.854***	-143.9	13.42
	(0.046)	(0.051)	(0.071)	(0.057)	(97.18)	(8.463)
Observations	79	79	79	71	79	66
R-squared	0.680	0.663	0.645	0.767	0.734	0.749
Region FE	Yes	Yes	Yes	Yes	Yes	Yes

Note: Repeated cross-sectional (RCS) design: OLS estimator, 6 decades respectively. Dependent variable: (log) GDP per capita; Main independent variable: educational gender gap; Reference categories: British colonies, no immigration of workers; Robust standard errors (in parentheses) and regional fixed effects. Significance codes: *** p<0.01, ** p<0.05, * p<0.1. See Appendix for data construction and sources.

Table C.8: Female education and other correlates of real GDP per capita

Dependent variable:	Real GDP p.c. (log)			Real GDP p.c. (log)		
	1920-1929	1930-1939	1940-1949	1950-1959	1960-1969	1970-1979
	(1)	(2)	(3)	(4)	(5)	(6)
Female years of education	0.550***	0.322***	0.169***	0.118***	0.127***	0.119***
	(0.137)	(0.079)	(0.045)	(0.029)	(0.038)	(0.035)
Dummy if coast	-0.022	-0.017	0.019	0.153	0.169	0.116
	(0.226)	(0.261)	(0.277)	(0.146)	(0.222)	(0.231)
French colonies	-0.694**	-0.855***	-0.845***	-0.849***	-8.028*	-0.192
	(0.265)	(0.277)	(0.275)	(0.142)	(4.429)	(0.394)
Mandated territories	0.357	0.196	0.174	0.146	-1.188	0.789**
	(0.242)	(0.220)	(0.222)	(0.110)	(0.778)	(0.369)
Independent countries	-	-	-	-	-	-
Cash crop p.c. (log)	-0.038	-0.080	-0.106	-0.070*	-0.041	-0.047
	(0.066)	(0.093)	(0.102)	(0.041)	(0.040)	(0.039)
Minerals p.c. (log)	0.036	0.012	0.0003	-0.104	-0.360	-1.235
	(0.059)	(0.035)	(0.035)	(0.350)	(0.709)	(1.360)
Dummy if railroad	0.389***	0.238*	0.274**	0.191**	0.307***	0.474***
	(0.139)	(0.130)	(0.130)	(0.089)	(0.109)	(0.143)
Dummy if main mission 1924	0.341	0.433	0.428	0.050	0.139	0.128
	(0.239)	(0.266)	(0.294)	(0.240)	(0.247)	(0.260)
Tsetse suitability index	-0.038	-0.019	-0.016	0.032	-0.041	-0.075
	(0.098)	(0.090)	(0.095)	(0.084)	(0.125)	(0.134)
Population density (log)	0.013	0.019	0.031	-0.001	-0.028	-0.040
	(0.036)	(0.038)	(0.039)	(0.024)	(0.032)	(0.037)
Immigration of workers (little)	-0.588**	-0.560**	-0.600***	-0.325		
	(0.228)	(0.211)	(0.200)	(0.210)		
Immigration of workers (extensive)	0.213	0.303	0.279	0.268**		
	(0.201)	(0.201)	(0.214)	(0.108)		
Polity2					0.978*	-0.726*
					(0.524)	(0.402)
Polity2 sq.					0.189*	-0.071*
					(0.107)	(0.038)
Magnitude of civil war					3.277	0.057
					(2.026)	(0.058)
Life expectancy at birth (log)					47.97	-2.651
					(28.77)	(2.464)
Constant	6.832***	6.841***	6.798***	6.842***	-167.7	14.96*
	(0.045)	(0.049)	(0.062)	(0.042)	(104.8)	(8.885)
Observations	79	79	79	71	79	66
R-squared	0.680	0.660	0.645	0.767	0.731	0.748
Region FE	Yes	Yes	Yes	Yes	Yes	Yes

Note: Repeated cross-sectional (RCS) design: OLS estimator, 6 decades respectively. Dependent variable: (log) GDP per capita; Main independent variable: female years of education; Reference categories: British colonies, no immigration of workers; Robust standard errors (in parentheses) and regional fixed effects. Significance codes: *** p<0.01, ** p<0.05, * p<0.1. See Appendix for data construction and sources.

C.11. Appendix

C.11.1. Construction of database

For our sub-national empirical analysis, we retrieve individual-level data on male and female years of schooling completed from IPUMS International (Minnesota Population Centre 2019), which collects and distributes census data from around the world. While IPUMS-I provides 63 harmonized, representative census samples, covering ~10 percent of each country's population in 24 sub-Saharan African countries between 1960 and 2013, we restrict our sample to the earliest and latest census year for each country, recording age at enumeration, years of schooling completed and birth region of each individual[40]. Next, we limit our sample to those individuals aged 25-80 years at the time of the census. We set the lower bound at 25 because this is a reasonable age at which we can expect individuals to have completed schooling (Charles and Luoh 2003). Due to small sample sizes and the likelihood that the elderly overstate both age and education (Guntupalli and Baten 2006; Crayen and Baten 2010; Barro and Lee 2013), we also exclude individuals above 80 years from our study. This leaves us with 15.8 million individuals born in 1,107 administrative regions of 19 countries (Benin, Botswana, Burkina Faso, Cameroon, Ethiopia, Ghana, Guinea, Kenya, Lesotho, Liberia, Malawi, Mali, Rwanda, Senegal, Sierra Leone, South Africa, Tanzania, Uganda, and Zambia) retrieved from 32 national censuses.

The administrative birth regions included in our sample correspond to either first- or second-level geography, depending on their availability in IPUMS-I, and hence vary across countries (e.g., districts, regions, circles, etc.). To account for the different sizes of these administrative subdivisions we consider population size weights. The majority of these territorial divisions changed their geographic borders over the two census years we use for most countries. Calculations made at different spatial scales may convey different information. Put differently, analytic results may be distorted due to a change in scale caused by internal boundary shifting. To deal with this concern, IPUMS-I offers an integrated, year-specific geography variable providing information at the administrative unit level and the corresponding GIS boundary files.

To build our dataset we first identify the birth decade of each individual by subtracting

[40] For some countries including Burkina Faso, Ethiopia, Rwanda, and Sierra Leone we only have one census year available.

the individual's age from the year of the census enumeration. Consequently, we aggregate the individuals by their respective birth decade, sex, and years of schooling completed at an administrative subdivisional level. In order to stretch our cohort analysis back to the early 20th century and to avoid double counting of individuals, we keep the birth decades 1920 to 1950 from one early census year and the birth decades 1960 to 1970 from one late census year of each country. For some countries, including Burkina Faso, Ethiopia, Rwanda, and Sierra Leone we only have one census year per country from which we respectively derive all observed birth decades. Our final aggregated sample consists of 19 countries, 1,107 birth regions, and a total of 5,318 observations.

C.11.2. Measuring educational gender inequality

Based on this sample, we calculate our main variable of interest, the gender gap in educational attainment per birth region and decade, which we obtain by subtracting average female years of schooling completed from average male years of schooling completed. Note that we also construct the educational gender ratio by dividing the average number of school years completed among men by the average number of school years completed among women. Due to a positively skewed distribution of the educational gender ratio variable, we take the natural logarithm.

C.11.3. Measuring economic performance

At the level of birth regions contained in our sample, we construct our dependent variable, nighttime light intensity per capita. We use stable nighttime light data for the year 2013, which we obtain from the National Oceanic and Atmospheric Administration (NOAA 2020), and aggregate the sum of all digital number (DN) values of nighttime lights within a birth region. Since we are interested in using a per capita measure we divide these values by population data, obtained from the LandScan population distribution database (2013). As an additional measure, we aggregate the average of all digital number (DN) values of nighttime lights and construct a nighttime light per area (measured in square kilometers) variable. A detailed description of nighttime lights and the construction of this variable is provided in the main paper.

C.11.4. Measuring control variables

In the following, we give a detailed overview of the control variables included in our regression analyses. Original data have been obtained from multiple sources, however, some of these variables, including male educational expansion, colonial railroads, coast, colonizer identity, Christian missions, cash crop and mineral production as well as our main independent variable of interest, the educational gender gap, were already used in Baten, de Haas, Kempter, Meier zu Selhausen (2021).

Educational expansion. We use male years of education completed to control for overall educational progress in sub-Saharan African regions. We obtain data on schooling for male individuals from IPUMS censuses and calculate the average number of school years among men per region and birth decade.

Trading location. Based on a coastal GIS map, we construct a binary coastal variable that takes the value 1 if a sub-Saharan African birth region is located on the coast and 0 in case it's being landlocked.

Colonizer identity. We create a dummy for the colonizer's identity for territories being ruled by the British (Ghana, Guinea, Malawi, Nigeria, Sierra Leon, Uganda, Zambia), the French (Benin, Burkina Faso, Mali, Senegal, Western Cameroon), the League of Nations mandate (Cameroon, Rwanda, Tanzania), or were independent during (most of) the period considered (Ethiopia, Liberia, South Africa). We use British colonies as a reference category.

Cash crop and mineral production. To estimate cash crop and mineral output per district for each decade, we combine various sources. First, we collect country-level export volumes for nine important cash crops (palm oil, palm kernels, groundnuts, cotton, cocoa, coffee, tea, tobacco, and cloves) and three minerals (copper, gold, and diamonds) from 1920 to 1959 from the African Commodity Trade Database (ACTD; Frankema et al. 2018) and several other sources (Manning 1982; Mitchell 1995; Van Melkebeke 2017). Additionally, output data for agricultural commodities since 1960 are taken from the online database of the Food and Agriculture Organization. Mineral output in the period 1950-1979 is estimated based on 1957 output values from Hance et al. (1961), falling right into our period of interest. The included crops and minerals represent the most important exports from sub-Saharan Africa from c. 1920 to 1979, in terms of volume and value (Munro 1976). We exclude minor commodities, such as cashew nuts, copra, and maize. The included commodities were also almost entirely exported, with very limited domestic trade, which means that exports closely approximate total commercial output. Second, we digitize a map by Hance et al. (1961) that contains the source regions of 95 percent of exports across 38 countries in sub-Saharan Africa in 1957, conveyed as points at the site of production, which each represent an equal unit of value. This map gives the most comprehensive and consistent overview of the spatial distribution of export production in colonial tropical Africa. It was first digitized and employed by Roessler et al. (2020) to study the long-run effects of Africa's cash crop revolution on spatial inequality today. The authors of that study confirmed the accuracy of the map using data that they independently collected from colonial archives. The dataset covers twelve (groups of) agricultural products, as well as a wide range of minerals. Each of our crops and minerals of interest are included in the map individually, except for cloves, tea, and tobacco which are, together with khat and chilies (which were not exported in sufficiently large quantities to enter our dataset) collated under "other stimulants and spices". The ACTD and FAO allow us to estimate the relative contribution of these different crops to each country's output of 'other stimulants and spices'. Third, we intersect the Hance et al. (1961) map of African exports with our district borders to obtain a cross-sectional dataset containing the value of output per crop and mineral for each district in 1957. To obtain district-level time series from 1920 to 1979, we multiply country-level output for each year with the district-level value share in 1957 (district value / country value). This procedure is analogous but improves upon an approach used in various recent papers, which all have to deal with an absence of panel data on sub-national cash crop and mineral production (Jedwab and Moradi 2016; Papaioannou and de Haas 2017; Tadei 2020; Jedwab et al. 2022). The main difference is that these earlier papers use agro-climatic or agro-ecological crop suitability as an indirect predictor of sub-national cash crop output, while we use the actual 1957 spatial distribution of output. As is the case with these other studies, our approach relies on the assumption that spatial patterns of crop-and mineral-specific output did not change much during our period of interest. This assumption is reasonable for several reasons. First, the source areas in 1957 are already extremely concentrated in a small number of districts (10 percent of the districts in our dataset produced 67.3 percent of all cash crops; 20 percent even produced 85.6 percent). It is telling that Hance et. al. (1961) refer to producing areas as "islands". Such islands included the Senegambia estuary, the forest zone of Ghana, the shores of Lake Victoria, and several islands in East and West Africa, which were known as centers of cash crop production throughout our period of interest. Second, cash crop output is closely related to fixed or sticky geographical features, such as soil fertility and market access (roads, railroads, and rivers) which were largely determined by 1920. Indeed, studies on the distribution of cash crops in the interwar era show a very similar pattern and the same core areas, although output quantities are not directly comparable due to district border changes (Papaioannou and de Haas 2017; Miotto 2019). Third, in a land-abundant, labor-scarce, and infrastructurally underdeveloped context, colonial states had an interest to concentrate output in specific regions and stimulate labor migration to those regions to save costs (cf. Roessler et al. 2020), which lends further credibility to the existence of relatively fixed 'islands' of production. It should also be noted that even if some measurement error remains, our variable which captures actual production mid-20th century is more precise than indirect measures based solely on crop suitability. Fourth, we sum cash crop output and mineral value for each district and each year respectively and generate decadal averages for both variables. It should be noted that many districts did not export any of the nine crops and three minerals included in our dataset. Botswana and Zambia did not harbor any cash-crop exporting districts, hence we assign zeros. South Africa and Lesotho's cash crop locations are not covered by Hance et al. (1961) and thus their 10 districts are dropped from the regression analysis.

Infrastructure. We account for infrastructure by constructing a railroad dummy variable based on the GIS database used in Jedwab and Moradi (2016). The dummy variable for colonial railroads takes the value 1 if a birth region had access to railroads during a certain decade, 0 otherwise.

Christian missions. Based on the published map by Roome (1925) which was later digitized by Nunn (2010), we also control for the legacy of Christian missionaries (Catholic and Protestant) and construct a binary variable, which takes the value 1 if at least one mission station was present in a district, 0 otherwise.

Tsetse fly. We derive data on the tsetse fly from Alsan (2015) who has constructed the tsetse suitability index (TSI) which predicts the standardized steady-state population of tsetse flies. To build the TSI, Alsan (2015) used data on relative humidity and temperature averages of the year 1871 as well as results from laboratory experiments, which focused on analyzing suitable climate conditions for tsetse fly populations. The TSI coincides to a large extent with today's suitability of rain-fed agriculture and has its highest values at a temperature of about 25° C and about 88 percent relative humidity. Taking into account the entire African continent the TSI has its highest values in SSA, mainly in Eastern, Western, and Central Africa.

Population density. We include a historical population density variable whose data we obtain from the Hyde database. We aggregate the inhabitants per square kilometer and calculate the population per birth district and decade.

Initial economic development. To proxy initial economic development, we count the number of "cities" with above 10.000 habitants per administrative region in the 1920s. We obtain data for the city1920 variable from Africapolis, OECD (2020).

Labor migration. We obtain data on the migration of foreign workers during the colonial period from Ziltener et al. (2017). The variable contains three categories including no-, little- and substantial inflow of migrant workers. We construct three dummy variables, using no labor migration as our reference category.

Democracy. To measure democracy, we use the polity2 variable, an autocracy-democracy index ranging between -10 (total autocracy) and 10 (total democracy) from the Polity IV dataset. Data are yearly available, from 1960 onwards. Hence, we include this variable for the 1960 and 1970 decades. We also include a squared term since we find a non-linear relationship between the polity2 variable and nighttime light intensity per capita, our dependent variable.

*Civil violence and civil war***.** We obtain data for this variable from the systemic peace database. It measures the magnitude score of episodes of civil warfare and violence involving a respective state in a respective decade. The scale ranges from 1 (lowest) to 10 (highest) for each Major Episode of Political Violence (MEPV). 0 denotes no episodes. In the case of multiple MEPVs the magnitude scores are summed. Data on civil warfare and violence are available on a yearly basis, starting in 1960. We calculate an average magnitude score per region for the decades 1960 and 1970.

Life expectancy. We obtain data on life expectancy at birth from the historical UN database. Data are available on a yearly basis. Considering the period 1960 to 1979, we calculate decadal average values.

Fertility rate. We include a fertility (births per woman) variable at the country level. Data come from the World Bank and are available on a yearly basis from 1960 onwards. We calculate the average values per country for the 1960s and 1970s.

C.11.5. References

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C.11.6. Sample construction and robustness test

Table C.9: Number of birth regions and observations per country and census year

Country	Census year	Birth decades used	N Regions	Obs.
Benin	1979	1920-1950	76	304
Benin	2013	1960-1970	77	154
Botswana	2001	1920-1950	19	74
Botswana	2011	1960-1970	19	38
Burkina Faso	1985	1920-1960	30	150
Cameroon	1976	1920-1950	112	447
Cameroon	2005	1960-1970	306	612
Ethiopia	1984	1920-1950	85	340
Ghana	1984	1920-1950	10	40
Ghana	2010	1960-1970	10	20
Guinea	1983	1920-1950	33	132
Guinea	1996	1960-1970	34	68
Kenya	1969	1920-1940	41	123
Kenya	2009	1960-1970	156	312
Lesotho	1996	1920-1950	1	4
Lesotho	2006	1960-1970	1	2
Liberia	1974	1920-1940	11	33
Liberia	2008	1960-1970	15	30
Malawi	1987	1920-1950	26	104
Malawi	2008	1960-1970	31	62
Mali	1998	1920-1950	45	180
Mali	2009	1960-1970	46	92
Rwanda	2002	1920-1970	101	606
Senegal	1988	1920-1950	30	120
Senegal	2002	1960-1970	34	68
Sierra Leone	2004	1920-1970	66	396
South Africa	2001	1920-1950	9	36
South Africa	2011	1960-1970	9	18
Tanzania	1988	1920-1950	25	100
Tanzania	2012	1960-1970	30	60
Uganda	1991	1920-1950	34	136
Uganda	2002	1960-1970	56	112
Zambia	1990	1920-1950	52	207
Zambia	2010	1960-1970	71	142
Total			1,701	5,322

Table C.10: Overview of sample construction

Country	Census year	Fraction of pop., %	N_{all}	$N_{age\ 25\text{-}80,\ educ}$	$N_{age\ 25\text{-}80,educ}$ Male, %	$N_{age\ 25\text{-}80,educ,}$ Female, %	$N_{birth\ regions}$
Benin	1979	10	321,639	110,888	45	55	76
Benin	2013	10	973,181	319,358	46	54	77
Botswana	2001	10	160,837	61,276	46	54	19
Botswana	2011	10	192,303	80,472	46	54	19
Burkina Faso	1985	10	838,963	255,337	43	57	30
Cameroon	1976	10	530,720	192,928	46	54	112
Cameroon	2005	10	1,480,837	477,895	47	53	306
Ethiopia	1984	10	360,885	233,991	43	57	85
Ghana	1984	10	1,057,940	327,666	44	56	10
Ghana	2010	10	2,433,834	955,288	46	54	10
Guinea	1983	10	453,093	181,186	47	53	33
Guinea	1996	10	692,175	250,607	47	53	34
Kenya	1969	6	600,040	208,333	59	41	41
Kenya	2009	10	3,759,026	1,304,266	49	51	156
Lesotho	1996	10	187,795	72,124	47	53	1
Lesotho	2006	10	180,208	74,209	47	53	1
Liberia	1974	10	144,337	56,474	50	50	11
Liberia	2008	10	338,809	121,658	49	51	15
Malawi	1987	10	746,526	253,846	48	52	26
Malawi	2008	10	1,320,183	429,732	49	51	31
Mali	1998	10	973,938	310,729	46	54	45
Mali	2009	10	1,107,648	350,139	48	52	46
Nigeria	2006-10	0.6	426,395	166,202	49	51	-
Rwanda	2002	10	746,978	238,424	45	55	101
Senegal	1988	10	676,313	217,609	47	53	30
Senegal	2002	10	972,925	340,945	48	52	34
Sierra Leone	2004	10	362,402	131,737	46	54	66
South Africa	2001	10	3,643,062	1,653,673	45	55	9
South Africa	2011	8.6	4,102,679	1,919,113	45	55	9
Tanzania	1988	10	2,271,445	771,871	48	52	25
Tanzania	2012	10	4,481,851	1,597,048	47	53	30
Uganda	1991	10	1,505,350	473,690	48	52	34
Uganda	2002	10	2,457,456	764,287	51	49	56
Zambia	1990	10	665,468	230,340	47	53	52
Zambia	2010	10	1,234,750	411,452	49	51	71
Zimbabwe	2012	5	654,688	244,417	47	53	-
Total			43,056,679	15,789,210			1,701

Table C.11: Educational gender ratio and other correlates of regional GDP per capita, measured by nighttime light intensity per capita

Dependent variable:	Nighttime lights p.c. (log)			Nighttime lights p.c. (log)		
	1920-1929	1930-1939	1940-1949	1950-1959	1960-1969	1970-1979
	(1)	(2)	(3)	(4)	(5)	(6)
Educational gender ratio (log)	-0.020*	-0.050***	-0.058***	-0.070***	-0.062***	-0.070***
	(0.011)	(0.012)	(0.015)	(0.018)	(0.018)	(0.020)
Male years of education	0.029***	0.004	0.002	0.104***	0.020***	0.019***
	(0.011)	(0.007)	(0.007)	(0.026)	(0.004)	(0.005)
Dummy if coast	0.099**	0.092**	0.110***	0.113***	0.120***	0.117***
	(0.042)	(0.036)	(0.035)	(0.039)	(0.030)	(0.030)
French colonies	-0.198***	-0.135***	-0.125***	-0.134***	-0.147***	-0.054
	(0.050)	(0.043)	(0.035)	(0.037)	(0.049)	(0.053)
Mandated territories	-0.121	0.093	0.014	0.025	0.134**	0.038
	(0.078)	(0.081)	(0.063)	(0.076)	(0.061)	(0.085)
Independent countries	-0.184**	-0.051	-0.053	-0.006	-0.341***	-0.243***
	(0.080)	(0.075)	(0.065)	(0.078)	(0.061)	(0.062)
Cash crop p.c. (log)	-0.009	-0.009	-0.010	-0.009	-0.002	0.0001
	(0.009)	(0.009)	(0.008)	(0.007)	(0.003)	(0.0029)
Minerals p.c. (log)	0.318***	0.236***	0.243***	1.558***	1.905***	3.383***
	(0.028)	(0.015)	(0.015)	(0.120)	(0.136)	(0.245)
Dummy if railroad	0.101***	0.097***	0.113***	0.135***	0.130***	0.123***
	(0.029)	(0.025)	(0.022)	(0.024)	(0.018)	(0.018)
Dummy if main mission 1924	0.002	-0.004	-0.009	-0.007	-0.003	0.009
	(0.029)	(0.026)	(0.024)	(0.027)	(0.019)	(0.019)
Tsetse suitability index	0.009	-0.002	-0.007	-0.018	-0.038***	-0.038***
	(0.024)	(0.022)	(0.019)	(0.021)	(0.014)	(0.014)
Population density (log)	-0.030***	-0.025***	-0.023***	-0.016**	-0.0007	-0.003
	(0.008)	(0.007)	(0.006)	(0.007)	(0.0046)	(0.004)
Immigration of workers (little)	-0.034	-0.048	-0.039	-0.045		
	(0.034)	(0.034)	(0.027)	(0.030)		
Immigration of workers (extensive)	0.054	0.140***	0.099**	0.126***		
	(0.055)	(0.047)	(0.043)	(0.044)		
Polity2					0.066***	0.084***
					(0.008)	(0.010)
Polity2 sq.					0.010***	0.007***
					(0.001)	(0.001)
Magnitude of civil war					-0.059*	-0.002
					(0.030)	(0.009)
Life expectancy at birth (log)					2.334***	0.675***
					(0.234)	(0.210)
Constant	0.129	-0.057	0.034	-0.031	-8.594***	-2.265**
	(0.130)	(0.120)	(0.107)	(0.118)	(0.882)	(0.931)
Rho	0.819	11.30	2.782	18.59	1.600	1.604
	(1.137)	(350.2)	(11.37)	(46.46)	(4.398)	(3.312)
Observations	525	652	704	672	985	955
R-squared	0.391	0.478	0.491	0.425	0.440	0.430
Region FE	Yes	Yes	Yes	Yes	Yes	Yes

Note: Repeated cross-sectional regressions, 6 decades respectively using the SAR model. Regression models are corrected for spatial autocorrelation. Rho indicates the spatial autocorrelation coefficient. Dependent variable: (log) nighttime lights per capita (multiplied by 100 for readability); Main independent variable: educational gender ratio (log); Reference categories: British colonies, no immigration of workers; Robust standard errors (in parentheses) and regional fixed effects. Significance codes: *** p<0.01, ** p<0.05, * p<0.1. See Appendix for data construction and sources.

Table C.12: Educational gender gap and other correlates of regional GDP per capita, measured by nighttime lights per area 2013

Dependent variable:	Nighttime lights per km^2 (log)			Nighttime lights per km^2 (log)		
	1920-1929	1930-1939	1940-1949	1950-1959	1960-1969	1970-1979
	(1)	(2)	(3)	(4)	(5)	(6)
Educational gender gap	-0.237***	-0.358***	-0.370***	-0.175***	-0.137***	-0.111***
	(0.061)	(0.059)	(0.049)	(0.044)	(0.033)	(0.035)
Male years of education	0.299***	0.355***	0.281***	0.174***	0.094***	0.069***
	(0.045)	(0.038)	(0.029)	(0.026)	(0.016)	(0.017)
Dummy if coast	0.156	0.228*	0.238*	0.051	0.258**	0.345***
	(0.137)	(0.129)	(0.126)	(0.147)	(0.117)	(0.119)
French colonies	-1.281***	-1.22***	-1.150***	-1.364***	-0.701***	-0.667***
	(0.131)	(0.132)	(0.126)	(0.131)	(0.195)	(0.217)
Mandated territories	-0.901***	-0.802***	-0.866***	-1.008***	-0.121	-0.129
	(0.240)	(0.246)	(0.236)	(0.261)	(0.240)	(0.339)
Independent countries	-0.105	0.054	0.009	0.074	-0.820***	-0.933***
	(0.248)	(0.247)	(0.240)	(0.272)	(0.257)	(0.247)
Cash crop p.c. (log)	-0.046*	-0.081***	-0.087***	-0.055**	-0.023*	-0.008
	(0.027)	(0.031)	(0.029)	(0.024)	(0.013)	(0.012)
Minerals p.c. (log)	0.252***	0.089*	0.076	0.084	-0.060	-0.164
	(0.091)	(0.053)	(0.054)	(0.427)	(0.544)	(0.982)
Dummy if railroad	0.321***	0.333***	0.341***	0.354***	0.495***	0.523***
	(0.092)	(0.084)	(0.079)	(0.085)	(0.072)	(0.073)
Dummy if main mission 1924	0.240***	0.225**	0.212**	0.220**	0.197**	0.305***
	(0.092)	(0.090)	(0.089)	(0.097)	(0.077)	(0.077)
Tsetse suitability index	0.110	0.106	0.068	0.045	-0.109*	-0.073
	(0.072)	(0.072)	(0.070)	(0.074)	(0.059)	(0.060)
Population density (log)	0.081***	0.079***	0.088***	0.130***	0.095***	0.105***
	(0.023)	(0.024)	(0.023)	(0.025)	(0.020)	(0.019)
Immigration of workers (little)	0.151	0.158	0.161	0.188*		
	(0.103)	(0.104)	(0.101)	(0.103)		
Immigration of workers (extensive)	0.741***	0.747***	0.724***	0.559***		
	(0.166)	(0.163)	(0.156)	(0.162)		
Polity2					-0.019	-0.017
					(0.034)	(0.042)
Polity2 sq.					0.005	0.012**
					(0.005)	(0.005)
Magnitude of civil war					-0.501***	0.002
					(0.121)	(0.037)
Life expectancy at birth (log)					3.098***	3.093***
					(0.931)	(0.863)
Constant	0.945**	0.768**	0.815**	0.934**	-10.97***	-12.62***
	(0.388)	(0.385)	(0.374)	(0.402)	(3.504)	(3.788)
Rho	4.386***	5.695***	5.998***	1.105	1.077	1.121**
	(1.220)	(1.454)	(1.520)	(0.974)	(0.699)	(0.513)
Observations	716	717	717	678	985	955
R-squared	0.3296	0.3507	0.3721	0.3638	0.4270	0.4091
Region FE	Yes	Yes	Yes	Yes	Yes	Yes

Note: Repeated cross-sectional regressions, 6 decades respectively using the SAR model. Regression models are corrected for spatial autocorrelation. Rho indicates the spatial autocorrelation coefficient. Dependent variable: (log) nighttime lights per km^2 (multiplied by 100 for readability); Main independent variable: educational gender gap; Reference categories: British colonies, no immigration of workers; Robust standard errors (in parentheses) and regional fixed effects. Significance codes: *** p<0.01, ** p<0.05, * p<0.1. See Appendix for data construction and sources.

Table C.13: Data sources of regional GDP for robustness test

Code	Country	Type of data	Source
BEN	Benin	GDP	Data from HDR 2007/2008 and 2003
BFA	Burkina Faso	GDP	Data from HDR for GDP per capita
CMR	Cameroon	Expenditure	National Statistics Office
GHA	Ghana	Income	Data from Living Standards Measurement Survey Reports for 1998/9 and 1991/2
KEN	Kenya	GDP	Data from HDRs for 2006, 2005, 2003, 2001 and 1999
LSO	Lesotho	GDP	Data from HDR 2006
MWI	Malawi	Expenditure	Data from Malawi, Integrated Household Survey 2004-2005 and 1998
SEN	Senegal	GDP	Data from HDR 2001
TZA	Tanzania	GDP	National Statistics Office
UGA	Uganda	GDP	Data from HDR 2007
ZAF	South Africa	GDP	National Statistics Office (Table16)
ZMB	Zambia	GDP	Data from HDR 2007 and 2003

D. Uncovering the Role of Education in the Uptake of Preventive Measures against Malaria in the African Population

Abstract

In many African countries where malaria is endemic, this life-threatening disease is a leading cause of death. What role does education, in particular numeracy and literacy, play in malaria prevention and treatment-seeking? In this study we apply a birth cohort approach, which allows us to cover a time span of 60 years, and therefore, to provide a comprehensive view on the evolution of malaria prevention and treatment-seeking attitudes adapted among sub-Saharan African cohorts born during the 20th century. We use three different indicators to measure malaria control behavior: the share of respondents using insecticide-treated bednets (ITNs), the share of pregnant women taking antimalarial drugs, and the share of respondents taking their child to a medical facility when suffering from malaria symptoms like fever and cough. Our descriptive results suggest that younger birth cohorts are more likely to adapt malaria control measures than older ones.

Based on a sample of 33 African countries, 407 regions, and a total of 1,960 observations, we perform multiple regressions using the pooled OLS estimator. We find that being numerate as well as being literate is positively associated with malaria protection and health-seeking behavior, though the numeracy coefficients are of larger magnitudes indicating that numeracy is at least as important as literacy. While malaria prevention and treatment-seeking behavior is complex and influenced by unobservables, we cannot control for, we account for the most relevant factors like gender, socio-economic status, topology, and urban-rural settings. Our findings show that in addition to education, the involvement of women in health-care decision-making, as well as the exposure to media, is positively correlated with malaria control. On the other hand, we find that a low socio-economic status makes the adaption of adequate malaria prevention and treatment-seeking behavior more difficult. In highly elevated regions and regions with lower precipitation, where malaria is less prevalent, people seem to pay less attention to protection measures. Finally, while malaria is more acute in rural regions, in urban areas antimalarial drugs are also commonly used for protection.[41]

[41] This chapter is co-authored with Neha B. Upadhayay. She contributed approximately 20% to this research paper.

D.1. Introduction

In many countries where malaria is endemic, this life-threatening disease, caused by Plasmodium parasites and transmitted to the human body through the bites of female infected Anopheles mosquitoes, is a leading cause of death. The latest WHO reports (2020, 2021) suggest that in 2020 there were 241 million cases of malaria in 85 countries worldwide and over 620 thousand deaths related to the preventable disease. Ninety-five percent of these malaria cases and deaths occurred in the African continent.[42] The most vulnerable groups, which are at high risk of being infected with malaria, are pregnant women and children aged under five. In 2020, infants and young children accounted for 80 percent of all malaria death in sub-Saharan Africa.

Before the 1970s, the global approach to fight malaria was designated to implement vertical top-down malaria elimination programs, without paying any attention to the belief systems, traditions, and behavior of local communities. Interventions took place in the absence of integrating the affected populations. Many of these programs, however, failed to achieve their objectives, which is why during the global conference on primary health care in Alma Ata in 1978 it was decided to end the period of vertical disease control programs and instead focus on horizontal community-based strategies for malaria eradication. While medical know-how is certainly essential, the successful accomplishment of such strategies does also rely on comprehending malaria-related beliefs as well as socio-economic, cultural, political, and environmental factors that shape malaria prevention and treatment-seeking attitudes of individuals and entire communities. The dismissal or ignorance of these aspects has led to public health efforts being delinquent in the past (Heggenhougen et al. 2003). With human behavior playing an important role in malaria control, advances in applied malaria research should therefore not only be made in the medical field but contributions in socio-economic science may equally be helpful in filling malaria research gaps.

In this paper, we aim to address the role of education in malaria prevention and treatment-seeking behavior focusing on sub-Saharan Africa, a highly malaria-endemic region. We argue that basic numeracy and literacy skills may mitigate existing misconceptions about malaria (i.e., the disease is caused by excessive heat and overwork, Gessler et al. 1995; Ahorlu

[42] While a total of twenty-nine countries accounted for 96 percent of malaria cases globally, only six African countries including Nigeria (27 percent), the Democratic Republic of Congo (12 percent), Uganda (5 percent), Mozambique (4 percent), Angola (3 percent) and Burkina Faso (3 percent) were responsible for just over half of all malaria cases. In terms of deaths, in 2020 infants and young children accounted for 80 percent of all malaria deaths in sub-Saharan Africa.

et al. 1997; De la Cruz et al. 2006) and this way positively contribute to the adaption of malaria control measures. While there exist several options to measure malaria prevention and treatment-seeking behavior, we use the following three proxy variables: The share of respondents sleeping under insecticide-treated mosquito nets, the share of pregnant women taking antimalarials, and the share of respondents seeking medical treatment in case their child shows malaria symptoms.

Studies that have investigated the link between education, and malaria-related knowledge as well as treatment-seeking behavior (e.g., Kaona et al. 2000; Tarimo et al. 2000; Fawole and Onadeko 2001), frequently comprise cross-sectional country and region-specific analyses based on primary data. Our aim is to provide a more holistic but detailed view on malaria prevention and treatment-seeking behavior in sub-Saharan Africa, which is why we base our study on a sample including 33 countries, which are divided into 407 African regions. Considering a time span of six birth decades including the 1940s to the 1990s our dataset contains a total of 1,960 observations.

Most results obtained by existing studies, covering this research area, are solely based on descriptive evaluations, probably due to the usage of rather small sample sizes. In this respect, we apply an econometric approach, which allows us to attribute causality to our findings. Moreover, while previous research considers more the quantity aspect of education and relies on input measures as a proxy (i.e., years of schooling attained), we employ numeracy and literacy indicators, which allow us to capture the quality aspect of education and to uncover to what extent education actually has been absorbed by the individuals. Our findings show that while both factors exert a positive influence on malaria prevention and treatment-seeking behavior, being numerate is at least as important in terms of magnitude as being literate.

The remainder of this paper is structured as follows. In the subsequent section, the progress made in global malaria control is discussed. Section 3 provides an overview of the literature looking at the relationship between human capital and malaria knowledge as well as prevention behavior. Section 4 describes the data sources and the various variables used in the analyses. Section 5 discusses the methods applied. Section 6 provides a summary of our results followed by a discussion in section 7. Section 8 concludes.

D.2. Progress made in global malaria control

In a worldwide effort to control malaria, around 1.9 billion rapid diagnostic tests and almost 2.3 billion insecticide-treated mosquito nets were distributed during the last two decades of which over 80 percent were delivered to Africa. At the same time (2000-2020), there was a decline in an estimated 1.7 billion cases and 10.6 million deaths related to malaria.

The rise in global attention towards malaria elimination has put forth global alliances of organizations such as the Multilateral Initiative on Malaria (MIM) and global partnerships like the Roll Back Malaria (RBM). These involve different actors committed to combat malaria including community health workers, researchers and academic institutions, malaria-endemic and donor countries, private sector, non-governmental, and international donor agencies, which have contributed millions of dollars to malaria research.

The Global Technical Strategy for malaria (GTS) 2016-2030, which was introduced by the World Health Assembly in 2015, aims at guiding countries in their progress towards malaria eradication. It sets out estimates of funding to achieve milestones related to the reduction in case incidence and mortality rate for the years 2020, 2025, and 2030. Total funding for malaria control and elimination was valued at US$ 3.3 billion in 2020, which was marginally higher than the 2019 figure of US$ 3.0 billion. Nevertheless, the money invested in 2020 fell short by US$ 3.5 billion since a global amount of US$ 6.8 billion was estimated to be required to stay on course towards the GTS milestones. The gap in funding needed and awarded funds has been progressively widening (from US$ 1.3 billion in 2017 to US$ 2.3 billion in 2018 to US$ 2.6 billion in 2019, and to US$ 3.5 billion in 2020). The funding remains concentrated in the area of drug development (36 percent of malaria funding between 2007-2018), followed by basic research (26 percent) and vaccine development (25 percent). Investments in vector control products and diagnostics were notably lower at 6.2 percent and 2.5 percent respectively (WHO 2020, 2021). The recently developed and first approved malaria vaccine by the World Health Organization is inter alia a successful outcome of the pooled funding invested in malaria control and elimination efforts.

D.3. Literature review

There is consensus amongst researchers that the human response to malaria and control programs is crucial to the success of malaria control strategies. This is also particularly relevant since a better grasp of health-seeking and treatment behavior can lead to more effective health communication strategies for malaria and the promotion of early and effective treatment of clinical cases, especially among young children and pregnant women, who are most at risk of being infected with malaria.

There have been few systematic studies of how episodes of malaria are recognized and treated both, at the household and individual level. It is crucial to know how people, especially mothers and caretakers of young children, make decisions about whether to administer home remedies, consult traditional healers, or go to a clinic or hospital. Without information on health-seeking behavior, it would be difficult to develop an integrated strategy for reducing malaria infection and mortality.

The beliefs about the cause and transmission of malaria vary across societies according to educational, cultural, and economic factors, exerting influence on both preventive and treatment-seeking behavior. It is essential to take these perceptions into account and to address them since beliefs, deviating from correct scientific knowledge concerning the cause and transmission of malaria may hinder or delay appropriate treatment-seeking. In the worst-case scenario, they may lead to no actions being taken at all, which in turn can have serious consequences. For instance, research has shown that in some cases young children are deprived of insecticide-treated bednets due to the misconception that insecticides could also have toxic effects on children since they kill insects (Winch et al. 1997). Another example refers to the ingestion of bitter substances such as chloroquine, an antimalarial drug, which should be avoided during pregnancy on the grounds that bitter substances would cause miscarriage (Ndyomugyenyi et al. 1998; Launiala 2007).

While cultural traditions and beliefs should be respected, the provision of education and the development of numerical skills, including critical thinking ability, may contribute to the mitigation or even eradication of such misconceptions about malaria and therefore foster proper malaria prevention and treatment-seeking behavior. There is some evidence showing that education is positively associated with the acquisition of malaria-related knowledge (Kaona et al. 2000; Fawole and Onadeko 2001). In Africa, mothers are perceived as primary caregivers in the household and often first recognize when children fall sick by interpreting bodily and behavioral changes (Kidane 2000). They also believe to know when it is urgent to seek medical treatment and in which cases home remedies are effective (Mwenesi et al. 1995a). Evidence, however, shows that home treatment can result in taking inappropriate dosages of medication or prevent from getting patients to health facilities in time, in case their condition worsens

(McCombie 1996). Besides, those who decide to “self-treat” tend to buy drugs from poorly informed sellers (Massele et al. 1993), sometimes even from primary school children who work as “shopkeepers” (Geissler et al. 2000). This indeed raises concerns about provided misinformation on appropriate treatment. Hence, to improve the effectiveness and success of malaria control strategies, primary attention should be paid to the behavior of mothers and caregivers when it comes to malaria prevention and treatment.

Literature on the relationship between education and malaria prevention attitudes or practices is inconclusive. De La Cruz et al. (2006) carried out a study about the use of mosquito nets in Ghana in which participants were asked questions about the cause and consequences of malaria, symptoms of the disease, risk groups, and ways of protection and treatment. Results show that survey respondents who protected themselves from malaria by using insecticide-treated bednets (ITNs) were not more knowledgeable about the disease than respondents who did not. In some cases, non-users of mosquito nets showed even more knowledge about malaria and its prevention than users, revealing that more education does not necessarily increase the usage of bednets. Dupas (2009) investigates what factors make rural households in Kenya invest in malaria prevention and finds no significant correlation between the educational level of household members and the take-up of malaria control devices. Koram et al. (1995) conduct a study in a peri-urban area of the Gambia exposed to seasonal malaria transmission. Based on a sample of 350 Gambian children they find no association between malaria in children and the overall education level of the children’s parents or guardians. In Gabon, Kun et al. (1998) analyze a sample of 100 children suffering from severe malaria who were matched to 100 children with mild malaria symptoms, based on sex, age, and provenance. These children were tracked and the time until the first reinfection was documented. The authors were unable to detect a significant correlation between neither the severity of the disease nor the time to first reinfection and socio-economic factors including the mother’s level of education.

On the other hand, some researchers find evidence of education being important for malaria prevention and treatment. Tarimo et al. (2000) examine the perceptions and knowledge of mothers on childhood malaria in Tanzania, focusing on the Kibaha district. They conducted a cross-sectional survey in which the respondents were asked about potential symptoms they associate with malaria. Their results show a significant and positive correlation between the recognition of fever, some other malaria symptoms, and having at least completed primary education. 81.3 percent of mothers were aware of the fact that high fever is likely to cause convulsions and deteriorate the child’s condition. In addition, Tarimo et al. (2000) investigate the treatment-seeking behavior of caretakers. While mothers are at first inclined to cure their children with home remedies (e.g., bathing, giving paracetamol or aspirin, etc.), the study finds that in a second step 92.9 percent of mothers would seek medical treatment in a health facility. Further 98.3 percent claimed that laboratory tests were useful to confirm the diagnosis of their child being sick. Another 89.4 percent stated that laboratory tests were important in order to first recognize what kind of disease or parasites their child suffers from and second to be able to take appropriate and effective treatment measures. The perceived necessity by mothers of performing laboratory tests, resulting from the described reasons above, is positively associated with having completed primary or higher education. Fawole and Onadeko (2001) focus on Nigeria’s urban areas and analyze the treatment-seeking behavior of poor mothers and caregivers of children with fever. They find the education level to be a significant determinant of first aid sought. While 40.2 percent of mothers and caregivers with secondary education sought immediate treatment in a health facility, only 28.8 percent of those with no formal education visited a medical center. The majority of mothers with no education at all (52.6 percent) sought help from a traditional healer. Moreover, more educated mothers (41 percent) claimed to obtain drugs from patent medicine sellers (PMS) as compared to illiterate caregivers (25 percent). Kaona et al. (2000) carry out a KAP (Knowledge, Attitudes, and Practices) survey in the districts of Choma and Mporokoso, belonging respectively to the southern and northern provinces of Zambia. Based on data from 392 male and 415 female participants, the objective of this survey was to assess the respondents’ knowledge regarding the cause of malaria as well as their preventive actions taken against the disease. While the authors do not find a correlation between education and awareness of malaria transmission, the level of education is positively associated with the intake of chloroquine (as compared to traditional or no medicine) and other preventive measures taken. Schultz et al. (1994) conduct another KAP survey in Malawi to gather information on women’s use of antenatal clinic (ANC) services comprising malaria prevention and treatment during pregnancy. Using a sample of 809 pregnant women out of which 43 percent had no formal education and 70 percent had achieved below five years of schooling, the authors find education to be the only significant determinant of starting and pursuing ANC and giving birth in hospital.

Tobin-West and Kanu (2016) conduct a cross-sectional study, analyzing malaria prevention methods and their determinants among women of reproductive age (15-49) in Nigeria. While 89 percent out of 797 respondents showed a sound knowledge of malaria, which was significantly correlated with their educational level, the usage of mosquito nets was not at its full potential. Approximately half of the respondents (49.3 percent) owned a bednet out of which 88.3 percent were insecticide-treated (ITNs). However, only 18 percent of ITN owners used them consistently. Choonara et al. (2015) investigate, based on the Demographic and Health survey (2008-2009), factors determining the usage of ITN's among 622 pregnant women in Kenya. They apply a multivariate regression analysis and while their results show no effects of education on intermittent preventive therapy (IPTp), which can be employed as a malaria preventive measure during pregnancy, educational achievement exerts, besides other factors, a positive influence on ITN usage.

Safeukui-Noubissi et al. (2004) review in a matched case-control study the risk factors for severe malaria in Bamako, a district of Mali. Mothers of a total of 390 children participated in the survey. While 130 children were severely affected by malaria (cases), the remaining 260 children served as a control group. In contrast to Koram et al. (1995) and Kun et al. (1998), the findings of this study reveal that maternal education, as well as mothers' malaria-related expertise, are associated with a substantial decrease in the risk of children being infected with malaria. Yakum et al. (2020) carry out a study at the household level in the Northwest Region of Cameroon and look at the socio-economic determinants of behavioral adaptions to malaria control. Based on data from 400 households in ten districts with high malaria prevalence, the authors estimate a behavioral logit model of malaria prevention demand, whereby demand is defined as the likelihood of adapting various kinds of malaria prevention practices. Their findings show that inter alia the educational attainment of household heads has a positive influence on the number as well as the type of prevention measures adopted. Households, whose head has secondary or tertiary education, adapt with a higher probability more malaria prevention options and choose with a higher likelihood more holistic prevention options than those whose household head has completed only primary education.

Similarly, some researchers find that education matters by observing a significant negative correlation between low or no education and malaria-related behavior. A study in Brazzaville, the capital and region situated in the Democratic Republic of Congo, concludes that the odds of cerebral malaria were 90 percent higher among children whose mothers have not completed primary education (Carme et al. 1994). Evidence from Malawi shows that children and women in rural areas and with low education levels were more likely to suffer from fever than children from urban places and higher educated women (Ndawala et al. 2000). Another study, based on a sample of 672 households from the Blantyre district in Malawi, finds that households whose head has not obtained primary education were less likely to own mosquito nets (Holtz et al. 2002). Lastly, evidence from studies in different countries shows that lower education levels are associated with lacking knowledge about malaria, fewer prenatal check-ups, and hospital deliveries as well as fewer clinic visits (Carme et al. 1994; Macheso et al. 1994; Schultz et al. 1994; Slutsker et al. 1994; Mwenesi et al.1995a).

This comprehensive body of literature on the association between education and human behavior in malaria control shows that existing works restrict their analyses to individual countries, sometimes even single districts. As mentioned beforehand the goal of this paper is to obtain a bigger picture of malaria prevention and treatment-seeking behavior in sub-Saharan Africa, allowing for a cross-country comparison. We also want to highlight that, while previous research measures education with years of schooling completed or the overall level of education achieved, we provide a somewhat more nuanced distinction using numeracy and literacy measures. These output measures allow us to look at the particular implication of cognitive skills and critical thinking as well as being literate on human behavior related to malaria. Both, the capacity to read as well as numerical abilities are essential to understand health-related information, allowing to make smart healthcare choices and to take responsibility for one’s own and family’s health. In a medical context, the capacity to deal with words and numbers but also the capacity to read and act upon given information as well as being able to communicate health problems to medical providers and understand their health instructions is referred to as health literacy (Sørensen et al. 2012). We further elaborate on the importance of numeracy and literacy for malaria prevention and treatment-seeking practices in the discussion section. Finally, most studies we have come across during our research are correlational and therefore do not address simultaneity issues, which, however, cannot be ruled out in this case. It is indeed very likely that malaria control has a positive influence on education and cognitive skills. An adequate malaria protection and treatment behavior may reduce the likelihood of getting infected or if so, impede a severe course of the disease, which is often responsible for cognitive disorders and school absenteeism (Clarke et. al. 2008; Thuilliez et al. 2010; Nankabirwa et al. 2013). Consequently, if the burden of malaria decreases through active malaria control a positive influence on human capital accumulation can be expected. In this study, we attempt to establish a causal pathway and account for endogeneity by using the instrumental variable approach. The following section provides an overview of the data and variables used in our analysis.

D.4. Data and variables

To construct the database for our study we make use of four different types of surveys including the Demographic and Health Survey (DHS, years 1999-2020), the Malaria Indicator Survey (MIS, years 2006-2019), the Integrated Public Use Microdata Series (IPUMS, years 1969-2016) and Afrobarometer data (AFB, years 1999-2020).

The DHS together with the MIS data constitute our main data sources for variable construction, providing detailed information on malaria prevention and treatment-seeking behavior of respondents, the socio-economic background of individuals and households, demographics as well as relevant information on education, literacy in particular. The MIS surveys developed by the Monitoring and Evaluation Working Group (MERG) with the initiative to coordinate the worldwide fight for malaria control, are carried out during the high malaria transmission season and comprise questions and guidelines that are derived from DHS materials, with a particular focus on malaria-related questions. The DHS surveys can be divided into two types: The Standard- and the Interim DHS surveys. While the Standard DHS surveys are typically carried out every five years and are based on large sample sizes including between 5000 and 30,000 households, the Interim DHS surveys usually have smaller samples and shorter questionnaires than the standard DHS surveys since they only focus on key performance monitoring indicators. These surveys are distributed in various recode formats that allow for different units of analysis including women, children, households, etc., and come with geocoded information. We choose the Individual Recode (IR) that exclusively provides individual women’s data since this is the only recode providing malaria-related information. We employ these surveys, which come in waves, for 33 sub-Saharan African countries. In total, there are eight waves available. We use them from wave four onwards since questionnaires from earlier waves do not include malaria-related questions, which are of interest for the construction of our dependent variables. For each country, survey data from one or more waves are accessible. Table D.11 and Table D.12 in the Appendix provide an overview of data availability per wave for the DHS and MIS surveys, respectively.

We use data on numeracy and literacy to measure education, our primary explanatory factor. While DHS also provides us with data on literacy, we cannot rely on this data source to calculate age heaping-based numeracy estimates. The reason behind this is that enumerators carrying out DHS surveys do not rely on the respondents’ estimates but countercheck whether the age stated by the individuals is correct since DHS is particularly interested in the accurateness of demographic data. Except for minor variations, age data that were double-checked during the survey usually fail to reflect any age heaping, which is essential for our method applied and therefore become unusable for our purposes. Hence, we obtain age data from IPUMS and Afrobarometer, two data sources, which are not prone to verify the individuals' declared age. IPUMS provides 77 census samples on 26 sub-Saharan African countries between 1960 and 2016, covering around 10 percent of the countries' population. In addition, IPUMS offers large sample sizes of individuals within each country allowing for a more precise aggregation at the sub-national level. For countries for which no age data are available on IPUMS, we use additional data from Afrobarometer whose surveys, being conducted since the late 1990s, provide broad coverage of 37 countries but at the same time are based on smaller samples. Table D.13 in the Appendix presents IPUMS data availability per country and decade and Table D.14 gives us an overview on the countries' coverage by wave from the Afrobarometer surveys. Additional data sources, which we use for added controls include Kiszewski et al. (2004) who constructed a Malaria Ecology Index (MEI), Nunn and Puga (2012) from whom we obtain data on terrain ruggedness, McKee et al. (1993) who developed the Standardized Precipitation Index (SPI), Africapolis, (OECD/SWAC 2020) providing us with data on the urban dummy and the History Database of the Global Environment (HYDE 3.2), developed by Klein Goldewijk et al. (2017), from where we obtain data on pasture and cropland. Detailed information on all variables used in the analysis including their definition and construction is provided in Table D.1 and the summary statistics are displayed in Table D.2. Considering a minimum threshold of 30 individuals, we aggregate our individual data on 1,311,750 women by region and decade. Our final dataset is an unbalanced panel including 33 African countries, 407 regions at the first administrative level[43], six birth decades and a total of 1,960 observations.

D.4.1. Measuring malaria prevention and treatment-seeking behavior

Our dependent variable aims at assessing malaria prevention practices and treatment-seeking behavior across sub-Saharan African regions and birth cohorts. Therefore, we use three different proxies. The share of respondents who use insecticide-treated bednets is our main proxy. However, since especially young children aged under five and pregnant women are at high risk of contracting malaria (WHO 2020, 2021) we use two additional measures, namely the share of pregnant women taking antimalarial drugs and the share of respondents taking their child to a medical facility (public or private) in case it shows symptoms of malaria including

[43] Countries are divided into various administrative levels, whereby the first administrative division corresponds to the largest sub-national administrative unit of a country.

fever and cough. Figure D.1 displays the average of these three shares per country across all birth cohorts considered. Comparing them, we observe that the most commonly used method to protect against malaria in the majority of countries included in our sample is the usage of bednets (attaining slightly above 70 percent in Comoros). This finding is confirmed in existing literature (see Heggenhougen et al. 2003). Our descriptive statistics reveal that bednet usage is followed by the intake of antimalarial drugs (reaching around 40 percent in the Gambia). The share of respondents who take their child to a medical facility when it is sick and shows malaria symptoms such as fever and cough is shockingly low in all countries considered. It reaches at the most 10 percent in Burundi and Uganda.

Figure D.2 compares malaria prevention and treatment-seeking behavior for the 1950s and 1990s birth cohorts at the regional level[44]. We observe that the share of bednet users was very low among the 1950s birth cohort as compared to the share of bednet users among the 1990s birth cohort[45.] When considering pregnant women taking antimalarials, we again note an increase across the birth cohorts. In line with what we discover from our cross-country findings, the share of respondents seeking treatment in a medical facility when their child shows malaria symptoms is very low among the 1950s birth cohort and remains more or less constant across younger birth cohorts, without showing much evolution.

In addition, we would like to highlight that our sample includes countries where malaria is less endemic. We therefore also account for malaria suitability, which includes geographic and climatic characteristics making a country more or less suitable for malaria transmission. Figure D.3 gives an overview of malaria suitability across African regions and Figure D.4 depicts the correlation between malaria preventive behavior and malaria suitability. We observe that in countries, where malaria transmission risk is low (i.e., South Africa, Eswatini, Lesotho, Namibia, Ethiopia, and Lesotho), people are less eager to protect themselves from malaria.

In our analysis, we capture exclusively women's behavior related to malaria since malaria specific questions are only treated in the Individual Recode files, the woman's questionnaire. Literature shows, as previously mentioned, that children aged under five and women, in particular, pregnant women are the most vulnerable groups (WHO 2020, 2021). Malaria in pregnant women may not only profoundly affect the mother's and the developing

[44] The maps corresponding to malaria prevention behavior (bednet usage, antimalarial drug intake, medical treatment-seeking) of respondents among the 1940, 1960, 1970, and 1980 birth cohorts are provided in the Appendix Figures D.8, D.9, and D.10.

[45] We find that there is a monotonic increase in bednet usage across birth cohorts (1940s to 1990s).

foetus's health, often resulting in low birth weight of the newborn, but also increase the risk of malaria during infancy (McGregor et al., 1983). While women belong to the high-risk group, they also play a dominant role as mothers and caretakers being responsible for their family members' health (Rathgeber and Vlassoff, 1993). Thus, we do not regard missing men in our sample as a major caveat.

D.4.2. Measuring numeracy and literacy

Numeracy

We rely on the age heaping method to measure the numeracy component of human capital. To some extent, we are able to determine a person's cognitive ability, quantitative reasoning, or "numeracy" by looking at its ability to state his or her exact age. Individuals who lack basic numerical skills frequently struggle to correctly indicate their age and have a systematic tendency of rounding their ages to numbers ending in zero and five, known as age heaping. For instance, an individual may indicate to be 45 years old when in fact it is 43. This heaping phenomenon becomes visible when analyzing self-reported age data. Figure D.11 in the Appendix shows the example of two countries, South Africa where age heaping is low indicating that the society is highly numerate, and Nigeria where people have a higher tendency to heap their ages implying that the country's population has lower numeracy skills. Already back in the 1950s, Bachi (1951) and Myers (1954) used age heaping for influential demographic studies, demonstrating the inverse correlation between age heaping and education levels. In the economic history literature Mokyr (1983) was one of the first to apply age heaping, which later became a popular and widespread method used in various studies (Crayen and Baten 2010; Manzel et al. 2012; Hippe and Baten 2012; Stolz et al. 2013; Baten and Fourie 2015; Cappelli and Baten 2021). One major advantage of age heaping is that basic numerical abilities can be estimated even for early time periods where data on human capital are scarce or not available at all.

The age heaping method we employ in this study is based on the Whipple's index, which was initially introduced by George Whipple (1866-1924). For the calculation of the Whipple index, we first restrict the age range of individuals from 23 to 72. We exclude elderly people since they tend to overstate their age, which will bias our estimates. In addition, we drop individuals aged below 23, because younger individuals usually are more aware of their age since they have to report it more often on occasions like military service or marriage and therefore tend to heap less (Tollnek and Baten 2016). Moreover, in the case of children and adolescents, we do not know for sure whether they reported their ages themselves or whether their parents responded in their place (Manzel and Baten 2009). Second, we create age groups, starting respectively with the second digit 3 and ending with the second digit 2, such as 23-32[46]; 33-42 etc. We do not use common age ranges such as 20-29, 30-39 to avoid bias from people dying over time since there will be, for example, always fewer people who are 69 than 60 in a population. Third, we calculate the Whipple Index as the ratio of the sum of people reporting ages that end in a multiple of five to a uniform distribution assuming that one-fifth of the population actually does have an age ending in either 0 or 5. The resulting ratio is then multiplied by 100. The Whipple index is denoted as follows:

$$W = \frac{\sum(n_{25} + n_{30} + n_{35} + \cdots + n_{70})}{\frac{1}{5}\sum_{i=23}^{72} n_i} * 100$$

where i refers to the age of the individual. The yielded index ranges from 0 to 500.

While 0 indicates that no ages end in a multiple of five, 500 implies that all individuals reported an age ending in either zero or five. A value of 100 assumes no heaping and therefore reflects the “true”, even age distribution, where one-fifth of all stated ages actually is a multiple of five. This infers that a five-point rise in the Whipple Index is equivalent to a one percentage point increase in the share of heaped ages. To allow for a more intuitive interpretation we make a linear transformation of the Whipple Index and calculate the ABCC Index, which denotes the proportion of numerate individuals in the population.

$$ABCC = 1 - \frac{(W - 100)}{400} * 100 \; if \; W \geq 100 \,; else \; ABCC = 100$$

The ABCC Index allows us to obtain numeracy scores ranging between 0 and 100, where 100 implies being fully numerate. Since we are interested in comparing the evolution of numerical abilities across regions and birth cohorts, we aggregate the obtained ABCC values

[46] Individuals that belong to the age group 23-32 show a somewhat different heaping pattern than older individuals, tending to heap on even numbers (Crayen and Baten 2010). We, therefore, make an adjustment for this age group.

by administrative region and birth decade[47], ranging from 1940 to 1990.[48] Figure D.5 shows the spatial distribution of numeracy across African regions and time. We observe little evolution of numeracy over the birth cohorts. Numerical abilities have remained fairly constant, displaying a path-dependent pattern. We observe that numeracy levels in the southern part of Africa are very high, attaining scores between 90 and 100 already for the 1940s birth cohort whereas the Sahel region, Sudan and Ethiopia show lower numeracy levels.

While the age heaping method is commonly used, it is not free from potential caveats that need to be discussed. When using survey data one major concern is that the respondents, especially women, actually reported their age themselves and were not asked about their age in different ways to verify the accuracy of their answers, which would make data unusable for our purpose. To mitigate this issue, we rely on IPUMS census and Afrobarometer data, two data sources, which first of all are not gender-specific and secondly only ask for the respondents' age and not in addition for their birth year, which decreases the likelihood of counterchecking the individuals' correct age.

Another aspect that has led to some concern in the estimation of numeracy is that individuals may heap more as they advance in years. In other words, the same cohort of people may more likely heap their ages when they are in their sixties than in their twenties. Consequently, older birth cohorts would tend to have lower numeracy scores. To verify whether we observe this trend in our sample we compare numeracy scores for individuals that were born in the same decade but belong to various age groups[49]. Our results are displayed in Table D.3. While we obtain some significant coefficients, our results are not systematic and do not confirm that older age groups tend to heap more than younger ones. In other words, we can exclude the existence of an age bias in our sample.

Moreover, Földvári et al. (2012), Perrin (2020), and A'Hearn et al. (2022) question whether the marital status of women may bias numeracy scores. Their results show that age heaping is less common among married women than single women since they tend to orient themselves at their husbands' responses and adapt their age accordingly. This concern,

[47] We calculate the birth decades of the individuals by subtracting the age groups from the census years. Since we name the age groups from their lowest value (i.e., ages 23-32 are named age group 23) we add +5, which gives us the middle of each age group.

[48] If we obtain more than one ABCC value per region and birth decade, resulting from the fact that we have more than one census year per country available, we calculate the average weighted by the respective sample size.

[49] Respondents who were born in the 1950s for example were in their twenties when the census took place in the 1970s and in their sixties when the census took place in the 2010s.

however, is mitigated by Baten et al. (2022) who base their analysis on a large census data collection from Italy and find that the age heaping difference between married and single women is not systematic. Ferber and Baten (2021) look for the existence of a marriage bias in IPUMS samples including 26 sub-Saharan African countries but do not find any statistically significant results.

Finally, one of the concerns was brought up by A 'Hearn et al. (2021), namely that age heaping does not only occur in multiples of five and ten. Based on an Italian sample from the 19th century their results show that while individuals do heap on multiples of ten, they rather tend to heap on numbers ending in six than in five. This finding, however, seems to be specific to this particular sample. Ferber and Baten (2021) verify whether this heaping pattern also holds for African countries. Based on age data obtained from IPUMS, Afrobarometer, and MICS surveys, they verify the distribution of stated ages by individuals for each country and test whether there is any heaping evidence other than on multiples of five and ten. Their results show that this is not the case, except for younger individuals who tend to heap on multiples of two. Since we make use of the same data sources, this is thus not a concern we have to worry about and as mentioned beforehand, we correct for the youngest age group who tends to heap on even numbers.

Literacy

In addition to numeracy, we also investigate the role of literacy in malaria prevention and treatment-seeking behavior. We obtain data from the DHS surveys and define an individual as being literate if it is able to read entire as well as parts of sentences. We consequently construct our literacy share per region and birth decade. Figure D.6 shows the evolution of literacy in African regions across the birth cohorts considered. Similar to the numeracy levels, we observe that the share of individuals being able to read was already very high among the 1950s birth cohort in the southern part of Africa, ranging between 0.7 and 1.0, and remained at these high levels across subsequent cohorts. In the remaining African regions though we observe that the literacy rate was comparatively lower than the numeracy levels among the 1940s and 1950s cohorts and saw a more pronounced increase until the 1990s birth cohort. This measure certainly comes with its potential caveats. For example, the literacy rate does not tell us much about the distribution of literate individuals - whether they are highly concentrated and apart from the analphabetic population or rather evenly distributed across households. Therefore, we advise caution in its interpretation.

We find a very strong correlation between our numeracy measure and the literacy share as shown in Figure D.7. Additionally, it is important to investigate the relationship between malaria control and education indicators. Therefore, we provide a visualization of the correlation between the malaria prevention variables and numeracy as well as literacy (Appendix, Figure D.12). It is pertinent to highlight that these correlation graphs are not conditioned on malaria suitability, which might be an explanation for the outliers that we observe in these scatter plots.

D.4.3. Controls

We account for factors commonly found in the literature. Evidence shows that the socio-economic status as well as gender matters for correct treatment-seeking behavior. Caregivers who are often mothers and women in general are frequently the first to perceive symptoms of childhood malaria and are in charge of disease management in the household (Molyneux et al. 1999; Hausmann-Muela et al. 2000). Since our sample contains exclusively female individuals, we do not control for gender, but we account for the share of women who are involved in the household's healthcare decision-making. We further control for media usage in our regression framework. Findings in the literature indicate that the lack of knowledge and awareness of malaria is a major factor hindering prevention and treatment practices, which can be addressed to a large extent by using media communication tools (Ibidapo 2005; Mozumder et al. 2007; Ankomah et al. 2014). In many developing countries print and electronic media are popular means of behavior change communications. Especially among pregnant women who are most at risk of contracting malaria, mass media is used to address the benefits of the regular usage of bednets (Ankomah et al. 2014). While many studies conclude that knowledge is an essential predictor of prevention and treatment-seeking behavior, others find that socio-economic issues such as poverty play a more important role (e.g., Heggenhougen et al. 2003). Worrall et al. (2005) refer to malaria as the disease of the poor and find that the cost of treatment was one of the main obstacles in terms of accessing treatment. They conclude that the treatment expenses hit the poorest households the hardest and that they tend to seek care outside the modern sector (e.g., advice from friends, traditional healers) while wealthier households show a higher intake of antimalarial drugs and prefer to opt for modern sector treatment including public and private health care facilities. Hence, we account in addition for the poverty share. Finally, we control for seasonality by using rainfall data. We also add some geographic-related controls including the Malaria Ecology Index[50] to account for the severity of malaria across the different regions, terrain ruggedness measuring the altitude of a region since malaria is hardly or not at all prevalent in higher elevated regions and an urban dummy because urban areas have better housing facilities and provide limited options for the parasites to breed.

D.5. Methodology

D.5.1. Main regression analysis

To estimate our results, we apply a pooled regression model of the following form:

$$SAM_{itr} = \beta_0 + \beta_1 HumCap_{it} + X_{it}\Gamma + Z_i\Upsilon + \mu_r + \upsilon_t + \varepsilon_{it}$$

where SAM_{itr} denotes the share of respondents adopting the respective malaria prevention or treatment-seeking measure (i.e., usage of insecticide-treated bednets, antimalarial intake, seeking of medical care) in an administrative region *i* during decade *t*. β_0 indicates the constant term and β_1 measures respectively the impact of numeracy or literacy on the usage of malaria control measures. X_{it} comprises all time-variant controls (i.e., share of women in health care, media exposure, poverty rate, rainfall) whereas $Z_i\Upsilon$ is a vector of time-invariant controls (i.e., Malaria Ecology Index, terrain ruggedness, city dummy). We account for regional fixed effects (μ_r)[51] and decadal fixed effects (υ_t). ε_{it} denotes the error term.

D.5.2. Instrumental variable approach

While we account for a number of important factors, which are likely to influence behavioral aspects of malaria, we are also aware that there remain important potential determinants, especially cultural factors (e.g., communities' perceptions and beliefs about malaria causation and prevention, preference for traditional healers) we are unable to control for. These unobservables may lead to a potential omitted variable bias and hence be the source of

[50] The Malaria Ecology Index from Kiszewski et al. (2004) measures malaria suitability at the first-level administrative divisions of African countries and examines potential transmission stability. It represents the contribution of regionally dominant vector mosquitos to the force of transmission and depicts a region's resiliency to malaria perpetuation.

[51] For the regional fixed effects, we use the regional classification of Africa as suggested by the United Nations.

endogeneity. At the same time, a simultaneity bias may be present. As discussed previously, it is likely that our human capital variables are jointly determined with our dependent variable. Put differently, literacy and numeracy may not only influence malaria prevention and treatment-seeking behavior, but improved malaria protection may also lead to better educational outcomes and a decline in cognitive impairment. In order to mitigate both a simultaneous causality and omitted variable bias, we apply the instrumental variable (IV) approach using the log-ratio of pasture to cropland as an instrument. We argue that in regions, which benefit from a relative abundance of grazing, cattle farming is more prevalent (Boserup 1970) leading to a higher protein intake in pasture areas. In sub-Saharan Africa, animal source foods (ASF) are an important source of proteins enhancing nutritional adequacy (De Bruyn et al. 2016). An optimal protein supply plays a key role in early neural development. It boosts memory, optimizes brain health and cognitive functions, and is essential for learning (Giese et al. 2013). Our IV hence directly influences the learning capacity of basic numeracy and literacy and only affects our dependent variable (i.e., the share of people adopting malaria preventive behavior) by running through these human capital measures. Indeed, we cannot find any argument supporting the idea that the log-ratio of pasture to cropland has a direct effect on malaria prevention and treatment-seeking behavior. Unfortunately, research that has investigated the association between land cover classification and larval Anopheles habitats is rather scarce. Findings of some field studies in the Kenyan highlands reveal that the larvae of malaria mosquitos have been found more frequently in breeding sites on farm and pastureland than in forested areas (Minakawa et al. 2005; Munga et al. 2009; Mutuku et al. 2009). However, cropland covers were not found to have lower mosquito habitat suitability than pasture areas (Acheson et al. 2015). As aforementioned we use the Malaria Ecology Index to account for differences in transmission risk across regions. On the assumption that the exclusion restriction holds in our model and with the first stage F-statistics being way above 10, we consider this variable to be a valid instrument. Using the two-stage least-squares (2SLS) estimator we run an instrumental variable regression, with the first stage estimation being as follows:

$$HumCap_{itr} = \beta_0 + \beta_1 \, ln\,(\frac{pasture}{cropland})_{it} + X_{it}\Gamma + \mathrm{Z}_i\Upsilon + \mu_r + \upsilon_t + \varepsilon_{it}$$

where $ln\,(\frac{pasture}{cropland})_{it}$ denotes the grazing area of a region i relative to its cropland, varying across decades t.

D.6. Regression results

Our pooled OLS estimation results show clear evidence for a positive correlation between human capital, measured by numeracy and literacy, and malaria prevention and treatment-seeking behavior. We observe this positive relationship between education and malaria control in the case of all three proxy measures including the share of insecticide-treated bednet users, the share of pregnant women taking antimalarial drugs, and the share of respondents seeking medical care when their child suffers from malaria symptoms. Tables D.4, D.5, and D.6 display the regression results using respectively the various shares as the dependent variable. Starting with the share of bednet users, we obtain positive correlation coefficients of 0.26 in the case of numeracy and 0.23 in the case of literacy. In terms of antimalarial medication, a one percent increase in numeracy and literacy is associated with a respective increase of 34.5 and 9.7 percentage points in the share of pregnant women taking antimalarial drugs. Looking at treatment-seeking behavior we observe that a one percent rise in numeracy and literacy predicts respectively a 3.4 and a 0.7 percentage point higher share of respondents taking their child to a medical facility in case of fever and cough. Table D.7 displays the standardized numeracy and literacy coefficients. Considering all three dependent variables, numeracy shows, relatively to literacy, higher correlation coefficients, indicating a somewhat stronger relationship with malaria prevention and treatment-seeking behavior[52]. Our control variables are much in line with what is found in the literature. It seems that a higher share of women involved in health care decision-making is positively associated with malaria control behavior. This finding is significant at a 1 percent level and valid for all our malaria control measures. We further observe to some extent a positive correlation between the exposure to media (newspaper, radio, television, and internet) and malaria prevention behavior. In contrast, looking at the poverty share, we find evidence for a strong negative correlation between having a low socio-economic status and the behavioral aspects of malaria control, significant at a 1 percent level across all specifications. Urbanization does not show a clear pattern in relation to malaria prevention and treatment-seeking behavior. While in urban sites the share of pregnant respondents taking antimalarial drugs seems to be higher than in rural areas, we observe at the same time a negative correlation between the usage of bednets and living in the city. Finally, we control for potential factors determining the severity of malaria across sub-Saharan African regions including rainfall, the altitude of regions, and malaria suitability. Our results show that rainfall and malaria suitability are positively associated with prevention and treatment-seeking behavior.

[52] See Appendix Figure D.13 for a visual representation.

This means that in areas with higher rainfall and where malaria is more prevalent, the share of respondents using insecticide-impregnated bednets, taking antimalarial drugs, and seeking medical treatment tends to be higher. Similarly, we find a negative association between higher located regions, where malaria is less common or even non-existent, and protective behavior in response to malaria.

From the results of the instrumental variable approach, we infer that the direction, however not the size of the effect between our main variables of interest, measuring human capital, and our various dependent variables is causal. Findings of our instrumental variable regressions, which are displayed in the Tables D.8, D.9, and D.10, suggest a positive influence of both numeracy and literacy on all three measures of malaria prevention and treatment-seeking behavior considered, including the share of insecticide-treated bednet users, the share of antimalarial takers as well as the share of medical treatment seekers.

D.7. Discussion

Our regression results, which show positive effects of human capital on malaria prevention and treatment-seeking behavior, are in line with the findings of Choonara et al. (2015) who conclude that education is positively associated with the usage of insecticide-treated mosquito nets. In addition, we can also confirm the results of Kaona et al. (2000) who show that there is a positive relationship between the level of education and the adaption of malaria preventive measures including the intake of antimalarial drugs. Concerning treatment-seeking outcomes, we find in accord with Tarimo et al. (2000) and Fawole and Onadeko (2001), that education, more precisely numeracy and literacy, positively influences the caretakers’ decision to take their children to a medical facility when they suffer from fever and cough. While our regression results show that education plays an essential role in malaria prevention and treatment-seeking behavior, we also observe, that the magnitude of the standardized numeracy and literacy coefficients differs substantially. Being numerate seems to be relatively more important in economic terms than being literate.

Why might this be the case? In the healthcare environment, the ability to understand and use numbers is essential since many tasks (e.g., understanding dates and timing of medication dosage, measuring medications, refilling prescriptions) are numeracy-related. A closer look at how numeracy is defined in the literature shows that it involves, besides the ability to perform basic arithmetic calculations, a wide range of other skills including the understanding of risks and probability (Woloshin et al. 2001; Schwartz et al. 2005), the understanding of time, money and measurement (Rothman et al. 2008), cognitive abilities and quantitative reasoning (A'Hearn et al. 2022) as well as the capacity to apply mathematical skills in a particular situation, in other words, contextual oriented numeracy (Montori and Rothman 2005; Golbeck et al. 2005). How does this apply to malaria prevention behavior? With regards to the intake of antimalarial medication, it is certainly important to be able to understand medical directions containing numerical information concerning for example the dosage of drugs. Similarly, these abilities, especially the understanding of risk and time are essential when it comes to the recognition of malaria symptoms, the course and severity of the disease, and eventually the decision-making of seeking medical treatment. Indeed, it is important that caretakers recognize the risk children face once they show symptoms and are infected with malaria and that they also have a good sense of time when it comes to determining for instance the duration of convulsions or the time span in between. The correct usage of mosquito nets requires cognitive skills, in particular logical reasoning. Users have to understand how malaria is transmitted and why they actually should sleep under the bednets and keep them closed at all times. While this seems to be obvious, studies find that misconceptions about the cause of malaria, remain. In Tanzania and Ghana, for example, malaria is believed to be the result of overworking and heat (Gessler et al. 1995; Ahorlu et al. 1997; De la Cruz et al. 2006). In Uganda, poor diet and environmental conditions are among the perceived causes of malaria (Kengeya-Kayondo et al. 1994). In the Gambia and in Kenya malaria is associated with the possession of an evil spirit or the devil (Aikins et al. 1993; Mwenesi et al. 1995b). These mistaken beliefs may inter alia also explain the misuse of bednets, for example, for fishing (Minakawa et al. 2008; McLean et al. 2014) or playing football (Ntonifor and Veyufambom 2016). From another perspective, one could also argue that the understanding of probability as a component of numeracy is helpful to adopt correct preventive actions against malaria. The ability to think in probabilistic terms is notably important after contracting malaria in spite of the use of malaria prevention measures since it helps to comprehend that malaria prophylaxis and the use of mosquito nets remain important measures of protection, reducing the overall likelihood of getting infected with malaria.

While we cannot make causal claims with respect to our control variables, we can still discuss their correlations with malaria prevention and treatment-seeking behavior. Our results reveal a positive association between the share of women being involved in health care decision-making and malaria control behavior and are in line with the findings of Damaris Matoke-Muhia, a scientist focusing on malaria research at the Kenyan Medical Research Institute (KEMRI). According to her, it is the women, who do not only take care that high-quality mosquito nets are provided at the community level, but also make sure that they are used efficiently. In addition, as primary caregivers, they ensure that children who are infected with malaria receive and complete medical treatment. In some cases, however, women still may be prevented from taking the necessary health measures since they are often financially dependent and the ultimate decision-making power is not in their hands (Oberlaender et al. 2000; Heggenhougen et al. 2003). Instead, they have to get the permission from their husbands before being able to access malaria treatment (Molyneux et al. 2002). Under these circumstances, the price of insecticide-impregnated bednets and antimalarial medicine, such as chloroquine, frequently constitutes a major obstacle hindering women from buying malaria prevention products (Rashed et al. 1999).

We further find some evidence that the exposure to media (i.e., newspaper, radio, television, internet) is positively correlated with the share of pregnant women taking malaria prophylaxis and the share of respondents seeking medical treatment, which is in line with the findings of Bowen (2013), Ankomah et al. (2014), and Yaya et al. (2018). Media coverage can indeed be an excellent means of broadcasting health information and promoting various malaria prevention measures. In Nigeria, for example, mass media campaigns were initiated to raise awareness, particularly among pregnant women, on the effectiveness and long-term benefits of sleeping under insecticide-treated bednets during pregnancy (Ankomah et al. 2014).

Moreover, we observe that poverty and malaria control behavior are negatively interdependent, significant at a 1 percent level throughout all specifications. Despite massive efforts of achieving universal coverage of insecticide-treated bednet distributions, lower socio-economic status has been found to discourage the adaption of malaria prevention behavior. Berthélemy et al. (2013) provide evidence for the existence of a malaria trap, meaning that malaria reinforces poverty, which in turn makes it more difficult for the poor to deal with the disease and to seek protection and treatment.

In addition, Berthélemy et al. (2013) conclude that in areas where malaria is more prevalent, malaria protection behavior increases, which is in line with our findings. Indeed, in areas of high mosquito biting, people tend to protect themselves better using bednets, which in turn leads to lower malaria rates while in areas with a low mosquito biting nuisance, precaution and consequently the use of bednets decline, resulting in a higher rate of malaria (Thomson et al. 1996).

Lastly, we find an unambiguous correlation between urbanization and malaria control behavior. On the one hand, the share of bednet users seems to be lower in urban than in rural areas. This might be explained by the fact that malaria is, in general, more prevalent in rural areas where natural breeding sites, especially areas with stagnant waters, offer optimal conditions for mosquito vectors to proliferate. On the other hand, however, we observe that the share of pregnant women taking antimalarial drugs is higher in urban places. Although urbanization is supposed to reduce malaria transmission, the disease still persists in African cities, sometimes at more severe levels than in the countryside (Mattah et al. 2017) because containers or water tanks serve as breeding grounds (Heggenhougen et al. 2003). And while mosquito nets are commonly distributed in rural areas through free mass campaigns, antimalarial drugs are usually available in health facilities, pharmacies, and retail shops, which are more likely to be situated in urban sites.

The empirical findings discussed herein should be interpreted with caution in light of some limitations. First of all, the dataset we use for this study includes only women since both the DHS and the MIS surveys provide exclusively children's and women's data on malaria. Although most studies in this field base their analyses on female data because of various reasons (i.e., lack of sex-disaggregated malaria data, women are primary caretakers and more at risk), missing men in our sample hinder us from having a closer look at the underlying role of gender in malaria prevention and treatment outcomes. Pertaining our dataset, we also want to address the irregularities and frequency of the conducted surveys we employ. While the number of surveys carried out as well as the time interval between the individual surveys differ across countries, we consider the survey years together with the age of the women surveyed, to calculate six successive 10-year birth cohorts. Even though our cohort data, ranging from the 1940s to the 1990s, do unfortunately not allow us to consider the latest progress made in malaria prevention and treatment-seeking behavior, the time span of almost 60 years still makes it possible to look at the evolution of behavioral adaptions to malaria control across African regions.

Further limitations that need to be acknowledged concern our human capital variables, which are both generic indicators, measuring only very basic numerical and reading skills. Data availability does not allow us to distinguish between different performance categories such as basic, intermediate, or advanced literacy and numeracy. Despite the literacy rate being a commonly used method to measure reading and writing skills, concerns have been raised regarding its deficiency to account for different scenarios of distribution and therefore its potential failure to recognize the aggregate benefit of literacy if evenly distributed. A more even distribution of literate individuals across households, in contrast to fully literate or fully illiterate households, may indeed lead to greater effective literacy since illiterates benefit from living in a household where at least one person is literate (Basu and Foster 1998). The same is valid for numeracy. We employ the age heaping method to measure numerical skills, which is considered to be a reasonable indicator function for education. While the age heaping indicator, like other indicators of empirical research, certainly is subject to measurement errors, age heaping-based estimates are well suited for comparison with other educational estimates including literacy as we have seen in this study. We also acknowledge that not all samples are suited for age heaping analyses (Baten et al. 2022), notably due to substantial counterchecking of ages or the occurrence of sampling biases. Consequently, it is essential to thoroughly study the sample and carefully consider the sources where age data come from in terms of who collected data, who were the respondents, and how age data were obtained (i.e., questions asked).

Despite these limitations, we are able to ameliorate the scant literature on the relationship between human capital and the behavioral aspects of malaria prevention and control. Our study highlights the importance of collecting more robust and detailed data on human capital indicators that can be mapped to each household for a better understanding of factors that encourage malaria prevention and treatment-seeking practices. We provide further recommendations on malaria control in the following section.

D.8. Conclusion

Although there is no clear consensus, the role of human capital in this matter has been highlighted by several researchers (e.g., Tarimo et al. 2000; Fawole and Onadeko 2001; Choonara et al. 2015; Yakum et al. 2020). Hence, our paper studies the effect of numeracy and literacy on malaria prevention and treatment-seeking behavior. While literacy is essential for people's inspiration and capacity to access, comprehend and utilize information in manners, which advance and maintain health and wellbeing, numeracy is critical to a better understanding of healthcare-related tasks including for instance the measurement of fever, the dosage of medication and the frequency of administering drugs.

We use information from four different types of surveys including the Demographic and Health Survey (DHS), the Malaria Indicator Survey (MIS), the Integrated Public Use Microdata Series (IPUMS), and Afrobarometer data. Using a panel dataset including 407 African regions at the first administrative level, six decades, and a total of 1,960 observations, we find that education plays an essential role in malaria prevention and treatment-seeking behavior. Nevertheless, we also find that numeracy and literacy have different magnitude effects on malaria prevention and treatment-seeking behavior.

We also employ the Instrumental Variable approach to address any concerns regarding potential endogeneity arising due to simultaneity between our dependent variables and the education measures as well as unobservables like cultural factors. Our instrument is the log-ratio of pasture to cropland as it is believed to have a direct influence on learning capacities and affects our dependent variable (the share of people adopting malaria preventive behavior) only through the independent variables measuring human capital.

Our results highlight the importance of human capital attributes in the way malaria is prevented and treated in the African region. Despite our findings, however, we have to be aware of the fact that "correct knowledge" does not automatically imply that people change their perceptions or adopt a behavior, which would be considered by public health professionals to be in their self-interest. Human behavior is complex and sometimes tied to benefits related to other aspects than health. It is indeed not simply a consequence of knowledge and belief. We, therefore, have to be very cautious when we talk about education as "the solution" to improved malaria prevention behavior and as Good and Good (1993) pointed out, avoid thinking that we have to impart knowledge to people who "lack knowledge". However, we still believe that the development of human capital and cognitive skills may contribute to a substantial decrease in prevailing misconceptions about malaria.

We also report several findings of the control variables we include in our empirical analysis. We find that a higher share of women being involved in health care decision-making as well as exposure to media is critical for correct treatment-seeking behavior. On the other hand, a poor socio-economic status makes seeking protection and treatment difficult. We also find that while malaria is more prevalent in rural areas, urban areas also exhibit a high malaria persistence.

With the aforesaid findings, our paper has the following policy considerations: first, this study has highlighted the urgent need to focus on socio-economic and communication challenges associated with malaria and its prevention. The global work-stream on malaria needs to focus on avoiding conflicting advice and misinformation so that the response against not only malaria but also new diseases like the coronavirus is appropriate and effective amidst transmission in malaria-endemic settings.

Second, the enlistment and sustaining of political commitment (including for financial resources) for raising human capital levels to counter malaria are required. Therefore, investment in human resources should be given major attention. Malaria often occurs in villages and communities where health workers manage the disease at sub-center level. Therefore, the presence of a trained public health specialist in every district could play a vital role in malaria elimination and programs targeted at raising the local communities' education, awareness, and knowledge related to malaria.

Finally, health messages regarding malaria prevention and care should be conveyed from early stages in schools. This can be done by using, for example, audio and visual communication tools that educate children and through them also reach their caregivers. These public health intervention messages should be prepared with full engagement, including the participation of local communities. Keeping in mind that notably, numerical skills play an important role in malaria prevention and treatment-seeking behavior, schools should promote interest and achievement in learning mathematics and consequently rethink their curricula, placing a renewed focus on calculus. Over and above this, greater emphasis should be laid on linking theory to practice so that children learn how to apply numeracy skills in real-life situations.

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D.10. Tables and figures

D.10.1. Tables

Table D.1: Variable description and sources

Variable	Description	Comments	Data source
Share bednet (ITN) users	Share of respondents using insecticide-treated bednets (ITN's)	admin 1 level; time-variant	DHS and MIS surveys
Share antimalarial takers	Share of pregnant women taking antimalarial drugs	admin 1 level; time-variant; combination of variables denoting the intake of various antimalarial drugs	DHS and MIS surveys
Share treatment seekers	Share of respondents seeking treatment in a medical facility (public or private) when their children show malaria symptoms (fever, cough)	admin 1 level; time-variant; combination of variables	DHS and MIS surveys
Numeracy	Numeracy scores ranging from 0 to 100, whereby 100 implies being "fully" numerate	based on Abcc Index, admin 1 level, time-variant	IPUMS & Afrobarometer
Literacy	Share of people being literate	admin 1 level, time-variant	DHS and MIS surveys
Women in healthcare	Share of women being involved in health care decision	admin 1 level, time-variant	DHS and MIS surveys
Media exposure	Share of people being regularly exposed to media	admin 1 level; time-variant; combination of variables including exposure to the internet, newspaper, radio and television	DHS and MIS surveys
Share poor	Poverty share at admin 1 level	admin 1 level; time-variant	DHS and MIS surveys
Urban dummy	Dummy equals 1 if a region contains at least one city, 0 otherwise	admin 1 level; time-invariant; we consider towns with more than 10,000 habitants	(Africapolis, OECD 2020)
Malaria Ecology Index	Malaria suitability	average value at admin 1 level, time-invariant	Kiszewski et al. (2004)
Altitude (log)	Average value of terrain ruggedness	admin 1 level, time-invariant	Nunn and Puga (2012)
Rainfall	Average decadal rainfall	admin 1 level; time-variant	McKee et al. (1993)
Pasture / Cropland (log)	Log-ratio of pasture to cropland at admin 1 level	admin 1 level; time-variant	HYDE 3.2; Klein Goldewijk et al. (2017)

Table D.2: Summary statistics of variables

Variables	Obs.	Mean	SD	Min	Max
Share bednet users	1,960	0 .314	0.228	0	1
Share antimalarial takers	1,960	0 .222	0 .184	0	1
Share treatment seekers	1,960	0 .059	0 .047	0	0 .310
Numeracy	1,117	81.338	14.740	29	100
Literacy	1,960	0.445	0.300	0	1
Women in healthcare	1,960	0.245	0.219	0	1
Media exposure	1,960	0.107	0.121	0	1
Share poor	1,960	0.362	0.227	0	1
Urban dummy	1,960	0.322	0.468	0	1
Malaria Ecology Index	1,960	13.045	9.465	0	34.314
Altitude (log)	1,960	7.075	1.146	3.883	9.994
Rainfall	1,960	9.332	4.734	0	30.756
Pasture / Cropland (log)	1,941	4.473	8.944	0	94.076

Table D.3: Verification of age bias: numeracy scores by birth decade and age group

Birth Decade	ABCC					Differences									
	23-32 (1)	33-42 (2)	43-52 (3)	53-62 (4)	63-72 (5)	(1)- (2)	(1)-(3)	(1)-(4)	(1)-(5)	(2)-(3)	(2)-(4)	(2)-(5)	(3)-(4)	(3)-(5)	(4)-(5)
1940	82.693	79.411	80.697	76.977	66.801	3.282	1.996	5.715	15.892***	-1.286	2.433	12.610***	3.720 **	13.896***	10.177***
	(2.241)	(1.595)	(1.427)	(1.234)	(1.392)	(2.951)	(3.702)	(3.812)	(4.274)	(2.426)	(2.440)	(2.711)	(1.901)	(2.051)	(1.860)
1950	81.131	84.817	78.116	78.619	94.288	-3.687 *	3.015	2.512	-13.157	6.702**	6.199 ***	-9.470	-0.503	-16.172	-15.668
	(1.685)	(1.197)	(1.180)	(1.181)	(3.492)	(2.141)	(2.372)	(2.381)	(8.042)	(1.737)	(1.740)	(8.725)	(1.669)	(10.381)	(10.434)
1960	86.318	82.378	78.962	85.025		3.941**	7.357***	1.293		3.416**	-2.647		-6.063		
	(1.088)	(0.980)	(1.050)	(2.612)		(1.501)	(1.580)	(3.628)		(1.438)	(4.010)		(4.340)		
1970	82.847	82.834	79.857			0.0129	2.989			2.977					
	(0.936)	(0.867)	(2.423)			(1.274)	(2.405)			(0.203)					

Table D.4: Pooled OLS regression

DV: Share bednet (ITN) users	(1) pooled OLS	(2) pooled OLS	(3) pooled OLS	(4) pooled OLS
Numeracy	0.294*** (0.042)	0.256*** (0.040)		
Literacy			0.131*** (0.020)	0.232*** (0.023)
Women in healthcare		0.228*** (0.034)		0.170*** (0.030)
Media exposure		-0.151 (0.101)		0.040 (0.063)
Share poor		-0.159*** (0.022)		-0.164*** (0.025)
Urban dummy		0.003 (0.010)		-0.050*** (0.009)
Malaria Ecology Index		-0.0003 (0.001)		0.002** (0.001)
Altitude (log)		-0.056*** (0.006)		-0.032*** (0.005)
Rainfall		0.003*** (0.001)		0.003*** (0.001)
Constant	-0.003 (0.040)	0.103 (0.063)	0.239*** (0.013)	0.344*** (0.045)
Observations	1,117	1,117	1,960	1,960
R-squared	0.222	0.509	0.200	0.274
Region FE	No	Yes	No	Yes
Decade FE	No	Yes	No	Yes

Note: Robust standard errors in parentheses. Asterisks denote significance levels
*** p<0.01, ** p<0.05, * p<0.1

Table D.5: Pooled OLS regression (cont.)

DV: Share antimalarial drug takers	(1) pooled OLS	(2) pooled OLS	(3) pooled OLS	(4) pooled OLS
Numeracy	0.406*** (0.033)	0.345*** (0.029)		
Literacy			0.053*** (0.013)	0.097*** (0.015)
Women in healthcare		0.193*** (0.023)		0.102*** (0.028)
Media exposure		-0.021 (0.083)		0.254*** (0.046)
Share poor		-0.124*** (0.015)		-0.043*** (0.016)
Urban dummy		0.030*** (0.007)		0.037*** (0.008)
Malaria Ecology Index		0.002*** (0.00042)		0.003*** (0.001)
Altitude (log)		-0.020*** (0.004)		-0.019*** (0.004)
Rainfall		0.003*** (0.001)		0.002** (0.001)
Constant	-0.060* (0.034)	-0.112*** (0.041)	0.208*** (0.009)	0.217*** (0.032)
Observations	1,117	1,117	1,960	1,960
R-squared	0.321	0.709	0.282	0.327
Region FE	No	Yes	No	Yes
Decade FE	No	Yes	No	Yes

Note: Robust standard errors in parentheses. Asterisks denote significance levels

*** p<0.01, ** p<0.05, * p<0.1

Table D.6: Pooled OLS regression (cont.)

DV: Share medical treatment seekers	(1) pooled OLS	(2) pooled OLS	(3) pooled OLS	(4) pooled OLS
Numeracy	0.045*** (0.010)	0.034*** (0.008)		
Literacy			0.023*** (0.004)	0.007* (0.004)
Women in healthcare		0.038*** (0.007)		0.009 (0.006)
Media exposure		0.0003 (0.0340)		0.092*** (0.018)
Share poor		-0.038*** (0.004)		-0.037*** (0.004)
Urban dummy		0.001 (0.002)		-0.001 (0.002)
Malaria Ecology Index		0.0001 (0.0002)		-0.0002 (0.0002)
Altitude (log)		-0.004*** (0.001)		-0.003*** (0.001)
Rainfall		0.002*** (0.000)		0.001*** (0.000)
Constant	0.015 (0.009)	-0.027* (0.014)	0.051*** (0.003)	0.018** (0.009)
Observations	1,117	1,117	1,960	1,960
R-squared	0.021	0.428	0.023	0.375
Region FE	No	Yes	No	Yes
Decade FE	No	Yes	No	Yes

Note: Robust standard errors in parentheses. Asterisks denote significance levels
*** p<0.01, ** p<0.05, * p<0.1

Table D.7: Standardized coefficients of numeracy and literacy

Dependent Variable	Numeracy	Literacy
Share bednet users	0.180	0.163
Share antimalarial drug takers	0.266	0.157
Share medical treatment seekers	0.120	0.043

Table D.8: Instrumental variable regression

DV: Share bednet (ITN) users	(1) IV	(2) IV
FIRST STAGE		
Pasture / Cropland (log)	0.007**	0.007**
	(0.003)	(0.003)
SECOND STAGE		
Numeracy	0.122*	
	(0.068)	
Literacy		0.990***
		(0.098)
Women in healthcare	-0.086	0.520***
	(0.356)	(0.073)
Media exposure	-2.268	-0.176
	(1.836)	(0.113)
Share poor	-0.801	-0.259***
	(0.766)	(0.094)
Urban dummy	-2.327	-0.491**
	(2.486)	(0.234)
Malaria Ecology Index	-0.224	0.028**
	(0.172)	(0.012)
Altitude (log)	-1.199	-0.104
	(1.183)	(0.143)
Rainfall	-0.525	-0.036
	(0.563)	(0.072)
Constant	9.139	1.447
	(12.81)	(2.219)
Observations	1,111	1,941
R-squared		0.711
Region FE	Yes	Yes
Decade FE	Yes	Yes
F-Stat	75.92	88.1

Note: Robust standard errors in parentheses. Asterisks denote significance levels
*** p<0.01, ** p<0.05, * p<0.1

Table D.9: Instrumental variable regression (cont.)

DV: Share antimalarial drug takers	(1) IV	(2) IV
FIRST STAGE		
Pasture / Cropland (log)	0.007** (0.003)	0.008** (0.003)
SECOND STAGE		
Numeracy	0.151* (0.088)	
Literacy		0.016*** (0.002)
Women in healthcare	-0.102 (0.445)	1.337*** (0.116)
Media exposure	-2.570 (2.365)	0.594*** (0.211)
Share poor	-1.187 (0.985)	-0.750*** (0.143)
Urban dummy	-3.239 (3.231)	-0.490* (0.291)
Malaria Ecology Index	-0.291 (0.219)	0.012 (0.012)
Altitude (log)	-1.436 (1.521)	-0.205 (0.174)
Rainfall	-0.631 (0.734)	-0.099 (0.094)
Constant	11.13 (16.50)	3.001 (2.739)
Observations	1,111	1,889
R-squared		0.149
Region FE	Yes	Yes
Decade FE	Yes	Yes
F-Stat	75.92	84.3

Note: Robust standard errors in parentheses. Asterisks denote significance levels
*** p<0.01, ** p<0.05, * p<0.1

Table D.10: Instrumental variable regression (cont.)

DV: Share medical treatment seekers	(1) IV	(2) IV
FIRST STAGE		
Pasture / Cropland (log)	0.007**	0.007**
	(0.003)	(0.003)
SECOND STAGE		
Numeracy	0.026*	
	(0.015)	
Literacy		0.308***
		(0.031)
Women in healthcare	-0.038	0.195***
	(0.076)	(0.020)
Media exposure	-0.401	0.010
	(0.416)	(0.038)
Share poor	-0.223	-0.159***
	(0.170)	(0.026)
Urban dummy	-0.371	0.019
	(0.617)	(0.139)
Malaria Ecology Index	-0.042	0.012*
	(0.037)	(0.006)
Altitude (log)	-0.230	-0.023
	(0.266)	(0.087)
Rainfall	-0.098	-0.005
	(0.132)	(0.047)
Constant	1.482	0.161
	(2.860)	(1.389)
Observations	1,111	1,941
R-squared		0.281
Region FE	Yes	Yes
Decade FE	Yes	Yes
F-Stat	75.92	88.1

Note: Robust standard errors in parentheses. Asterisks denote significance levels
*** p<0.01, ** p<0.05, * p<0.1

D.10.2. Figures

Figure D.1: Share of people using bednets, taking antimalarial drugs and seeking medical treatment (average over 1940s to 1990s)

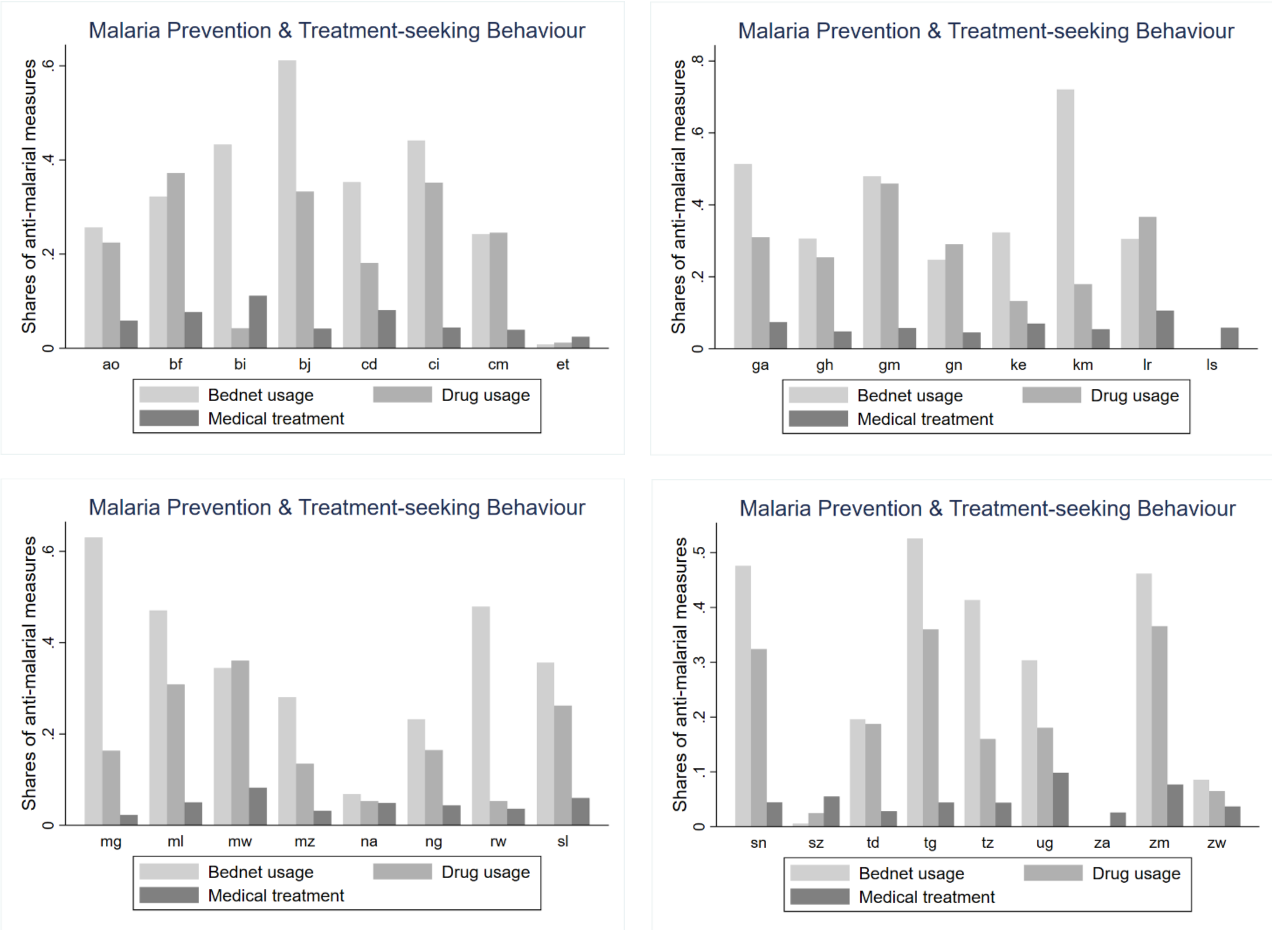


Figure D.2: Prevention and treatment-seeking behavior among the 1950s and 1990s birth cohorts at the sub-national level

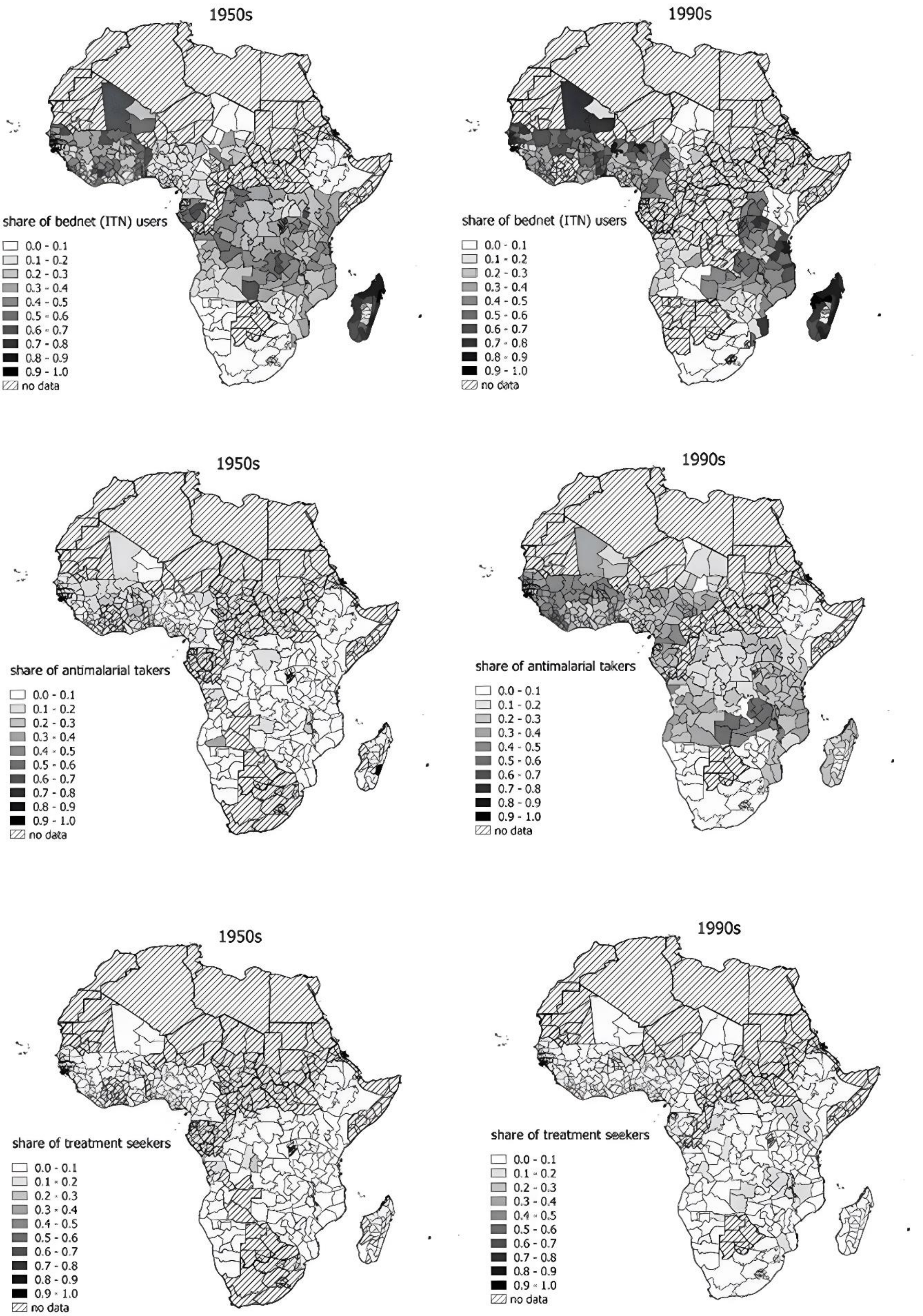


Figure D.3: Malaria suitability (ecology based) across African regions

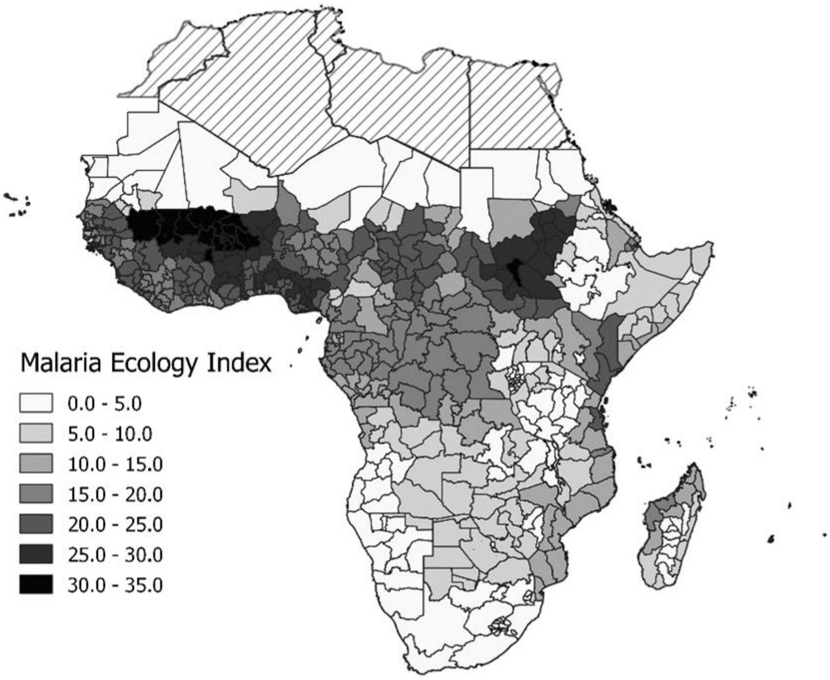


Figure D.4: Correlation between malaria prevention behavior and malaria suitability (average over 1940s to 1990s)

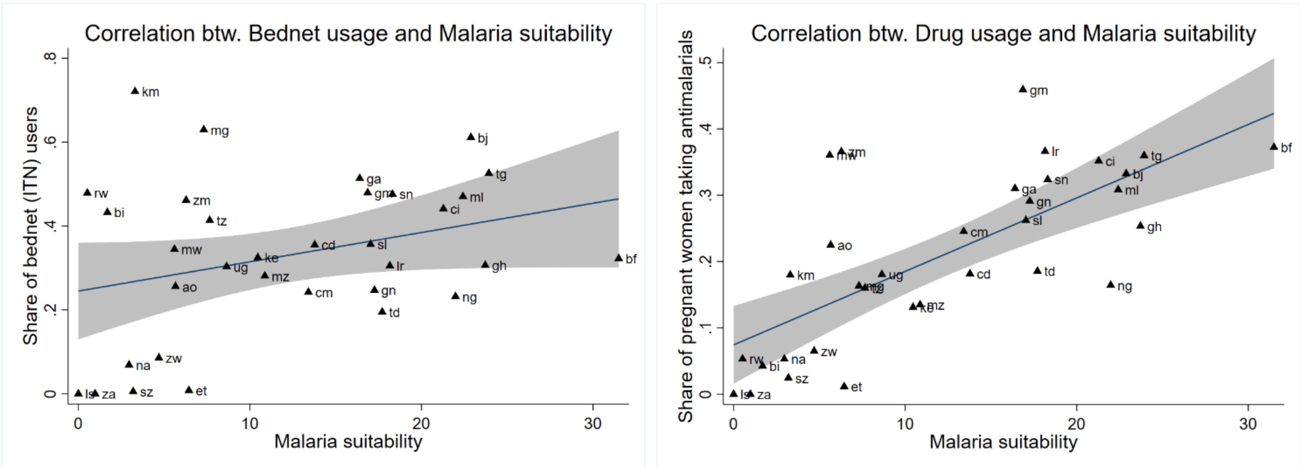


Figure D.5: Evolution of numeracy over birth cohorts (1940s to 1990s)

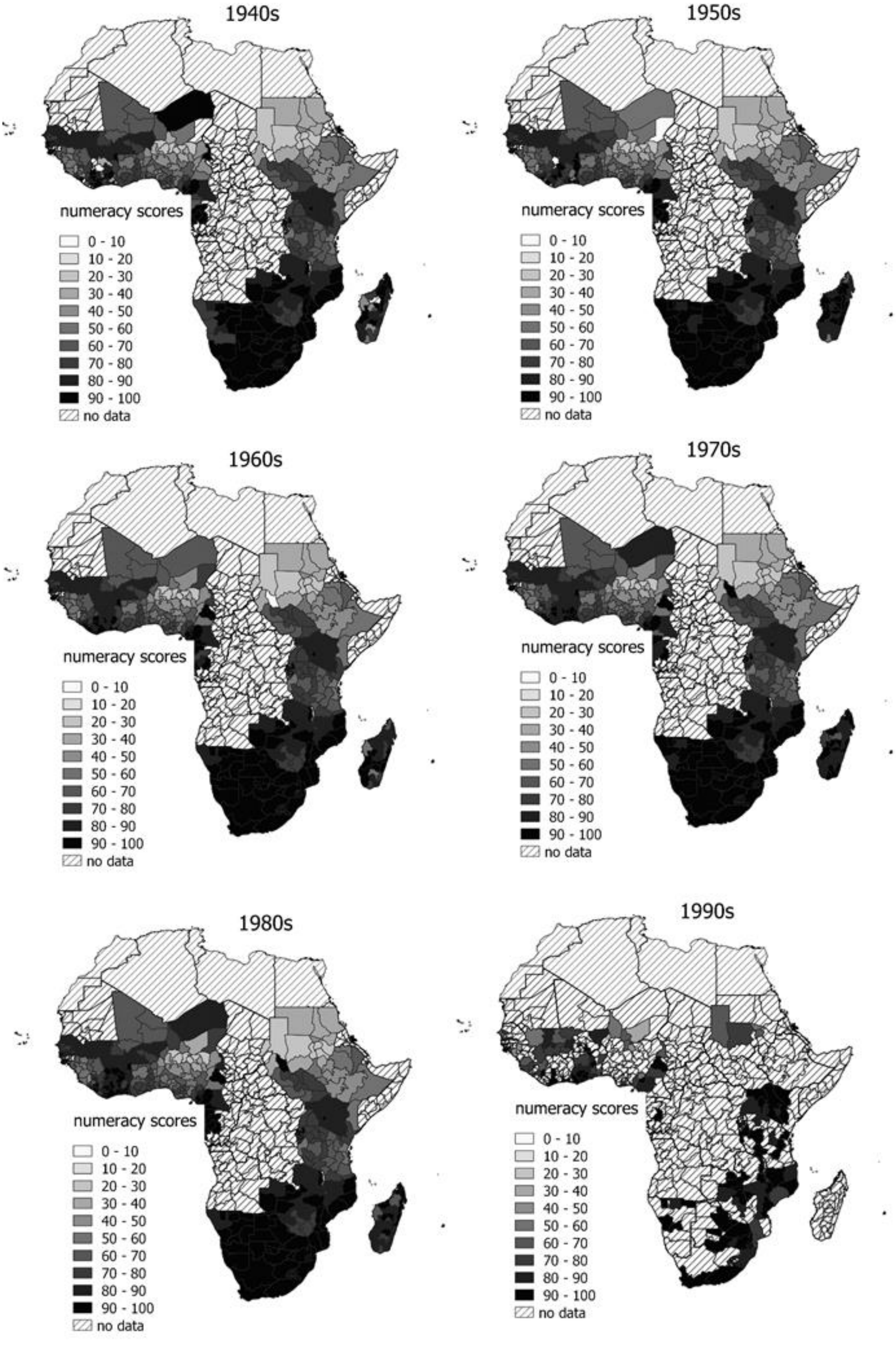


Figure D.6: Evolution of literacy over birth cohorts (1940s to 1990s)

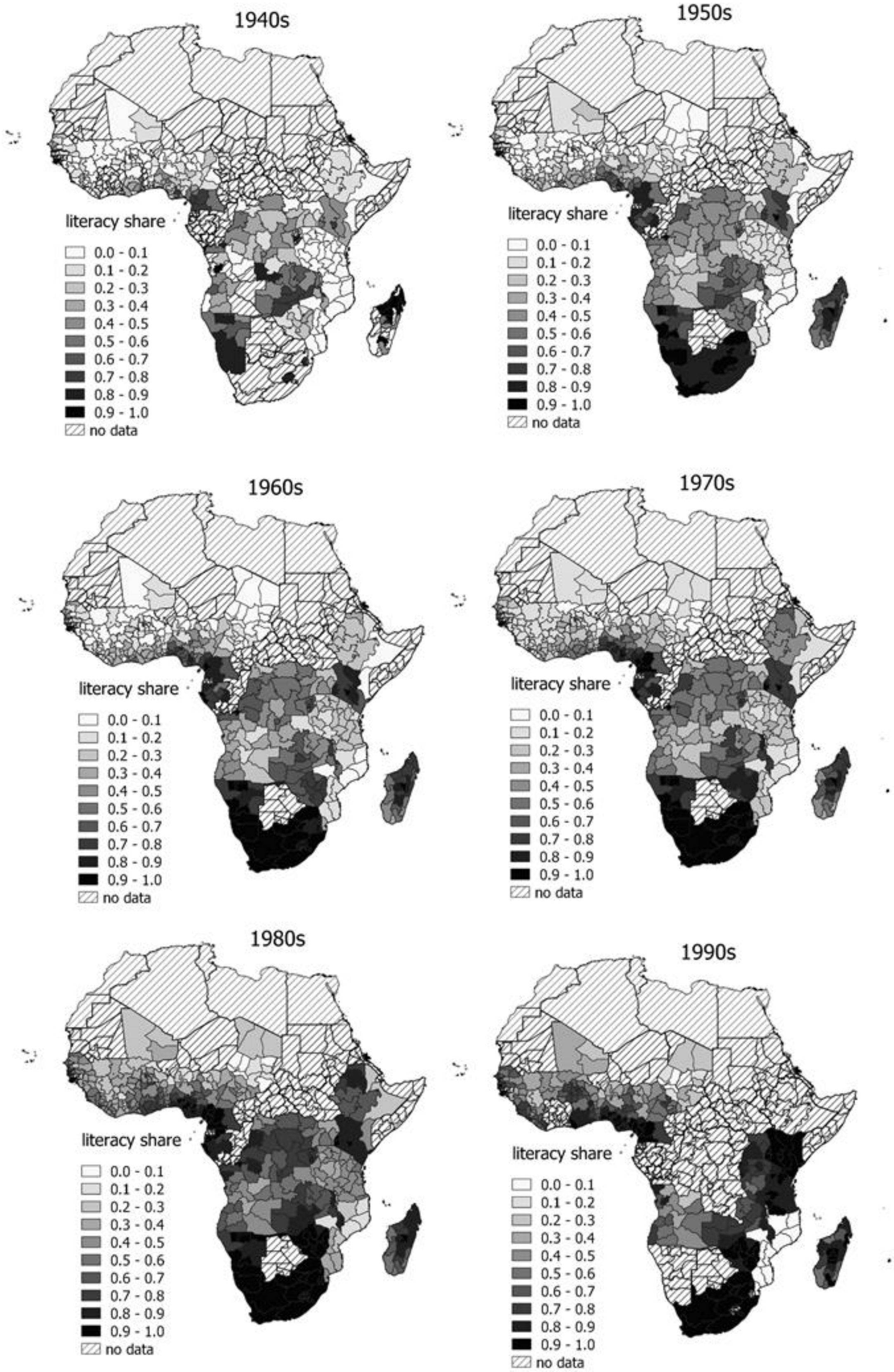
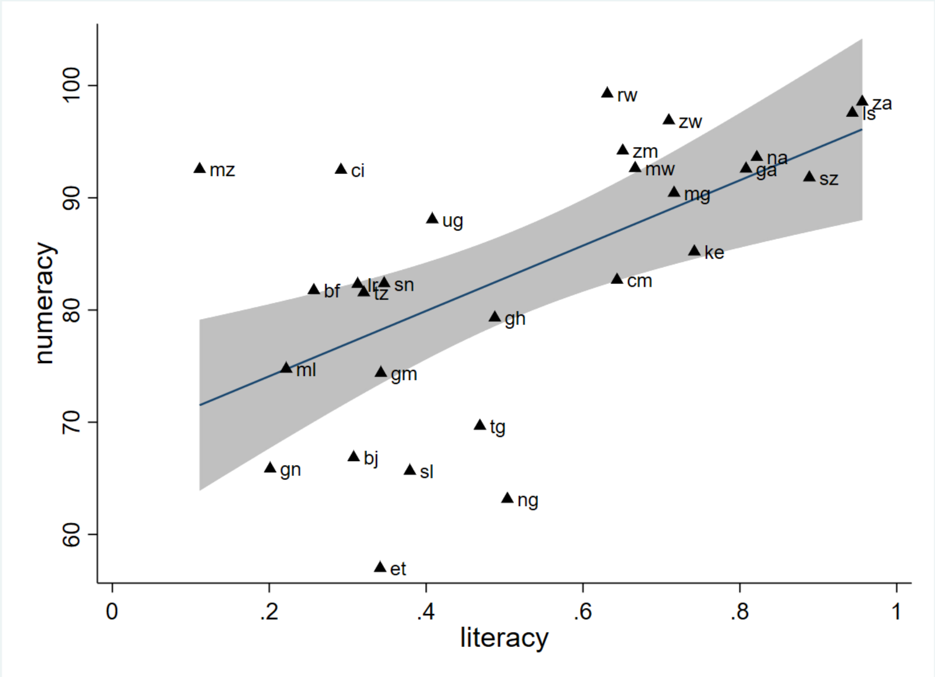


Figure D.7: Correlation between numeracy and literacy (average over 1940s to 1990s)



D.11. Appendix

D.11.1. Data availability

Table D.11: DHS data availability per wave

Wave 4	Wave 5	Wave 6	Wave 7	Wave 8
Benin	DR Congo	Benin	Angola	Ethiopia
Burkina Faso	Eswatini	Burkina Faso	Benin	Gambia
Cameroon	Ethiopia	Burundi	Burundi	Senegal
Ethiopia	Ghana	Cameroon	Cameroon	
Ghana	Guinea	Comoros	Chad	
Kenya	Kenya	Cote d‘Ivoire	Ethiopia	
Lesotho	Liberia	DR Congo	Ghana	
Malawi	Madagascar	Ethiopia	Guinea	
Mali	Mali	Gabon	Kenya	
Namibia	Mozambique	Guinea	Lesotho	
Nigeria	Namibia	Lesotho	Liberia	
Senegal	Nigeria	Liberia	Malawi	
Tanzania	Rwanda	Malawi	Mali	
Uganda	Sierra Leone	Mali	Mozambique	
Zimbabwe	Tanzania	Mozambique	Nigeria	
	Uganda	Namibia	Rwanda	
	Zambia	Nigeria	Senegal	
	Zimbabwe	Rwanda	Sierra Leone	
		Senegal	South Africa	
		Sierra Leone	Tanzania	
		Tanzania	Uganda	
		Togo	Zambia	
		Uganda	Zimbabwe	
		Zambia		
		Zimbabwe		

Table D.12: MIS data availability per wave

Wave 4	Wave 5	Wave 6	Wave 7	Wave 8
N.A.	Angola	Angola	Burkina Faso	Ghana
	Liberia	Burundi	Ghana	
	Senegal	Liberia	Kenya	
	Uganda	Madagascar	Liberia	
		Malawi	Madagascar	
		Nigeria	Malawi	
			Mali	
			Mozambique	
			Nigeria	
			Sierra Leone	
			Tanzania	
			Togo	
			Uganda	

Table D.13: IPUMS data availability per decade

1940	1950	1960	1970	1980	1990
Benin	Benin	Benin	Benin	Benin	Benin
Botswana	Botswana	Botswana	Botswana	Botswana	Botswana
Burkina Faso	Burkina Faso	Burkina Faso	Burkina Faso	Burkina Faso	Burkina Faso
Cameroon	Cameroon	Cameroon	Burundi	Burundi	Cameroon
Estwatini	Estwatini	Côte d‘Ivoire	Cameroon	Cameroon	Côte d‘Ivoire
Ethiopia	Ethiopia	Estwatini	Côte d‘Ivoire	Côte d‘Ivoire	Estwatini
Ghana	Gabon	Ethiopia	Estwatini	Estwatini	Ethiopia
Guinea	Ghana	Gabon	Ethiopia	Ethiopia	Gabon
Kenya	Guinea	Ghana	Gabon	Gabon	Ghana
Lesotho	Kenya	Gambia	Ghana	Ghana	Gambia
Liberia	Lesotho	Guinea	Gambia	Gambia	Guinea
Malawi	Liberia	Kenya	Guinea	Guinea	Kenya
Mali	Madagascar	Lesotho	Kenya	Kenya	Lesotho
Mozambique	Malawi	Liberia	Lesotho	Lesotho	Liberia
Nigeria	Mali	Madagascar	Liberia	Liberia	Malawi
Rwanda	Mozambique	Malawi	Madagascar	Madagascar	Mali
Senegal	Nigeria	Mali	Malawi	Malawi	Mozambique
Sierra Leone	Rwanda	Mozambique	Mali	Mali	Namibia
South Africa	Senegal	Namibia	Mozambique	Mozambique	Nigeria
Tanzania	Sierra Leone	Nigeria	Namibia	Namibia	Senegal
Togo	South Africa	Rwanda	Nigeria	Nigeria	Sierra Leone
Uganda	Tanzania	Senegal	Rwanda	Senegal	South Africa
Zambia	Togo	Sierra Leone	Senegal	Sierra Leone	Tanzania
Zimbabwe	Uganda	South Africa	Sierra Leone	South Africa	Togo
	Zambia	Tanzania	South Africa	Tanzania	Uganda
	Zimbabwe	Togo	Tanzania	Togo	Zambia
		Uganda	Togo	Uganda	Zimabwe
		Zambia	Uganda	Zambia	
		Zimbabwe	Zambia	Zimabwe	
			Zimabwe		

Table D.14: Afrobarometer data availability per wave

Wave 1	Wave 2	Wave 3	Wave 4	Wave 5	Wave 6	Wave 7
Botswana	Botswana	Benin	Benin	Benin	Benin	Benin
Ghana	Ghana	Botswana	Botswana	Botswana	Botswana	Botswana
Lesotho	Kenya	Ghana	Burkina Faso	Burkina Faso	Burkina Faso	Burkina Faso
Malawi	Lesotho	Kenya	Ghana	Burundi	Burundi	Cameroon
Mali	Malawi	Lesotho	Kenya	Cameroon	Cameroon	Côte d’Ivoire
Namibia	Mali	Madagascar	Lesotho	Côte d‘Ivoire	Côte d‘Ivoire	Eswatini
Nigeria	Mozambique	Malawi	Liberia	Eswatini	Eswatini	Gabon
South Africa	Namibia	Mali	Madagascar	Ghana	Gabon	Gambia
Tanzania	Nigeria	Mozambique	Malawi	Guinea	Ghana	Ghana
Uganda	Senegal	Namibia	Mali	Kenya	Guinea	Guinea
Zambia	South Africa	Nigeria	Mozambique	Lesotho	Kenya	Kenya
Zimbabwe	Tanzania	Senegal	Namibia	Liberia	Lesotho	Lesotho
	Uganda	South Africa	Nigeria	Madagascar	Liberia	Liberia
	Zambia	Tanzania	Senegal	Malawi	Madagascar	Madagascar
	Zimbabwe	Uganda	South Africa	Mali	Malawi	Malawi
		Zambia	Tanzania	Mozambique	Mali	Mali
		Zimbabwe	Uganda	Namibia	Mozambique	Mozambique
			Zambia	Nigeria	Namibia	Namibia
			Zimbabwe	Senegal	Nigeria	Nigeria
				Sierra Leone	Senegal	Senegal
				South Africa	Sierra Leone	Sierra Leone
				Tanzania	South Africa	South Africa
				Togo	Tanzania	Tanzania
				Uganda	Togo	Togo
				Zambia	Uganda	Uganda
				Zimbabwe	Zambia	Zambia
					Zimbabwe	Zimbabwe

D.11.2. Prevention and treatment-seeking behavior

Figure D.8: Prevention and treatment-seeking behavior (usage of bednets) for the birth cohorts at the sub-national level

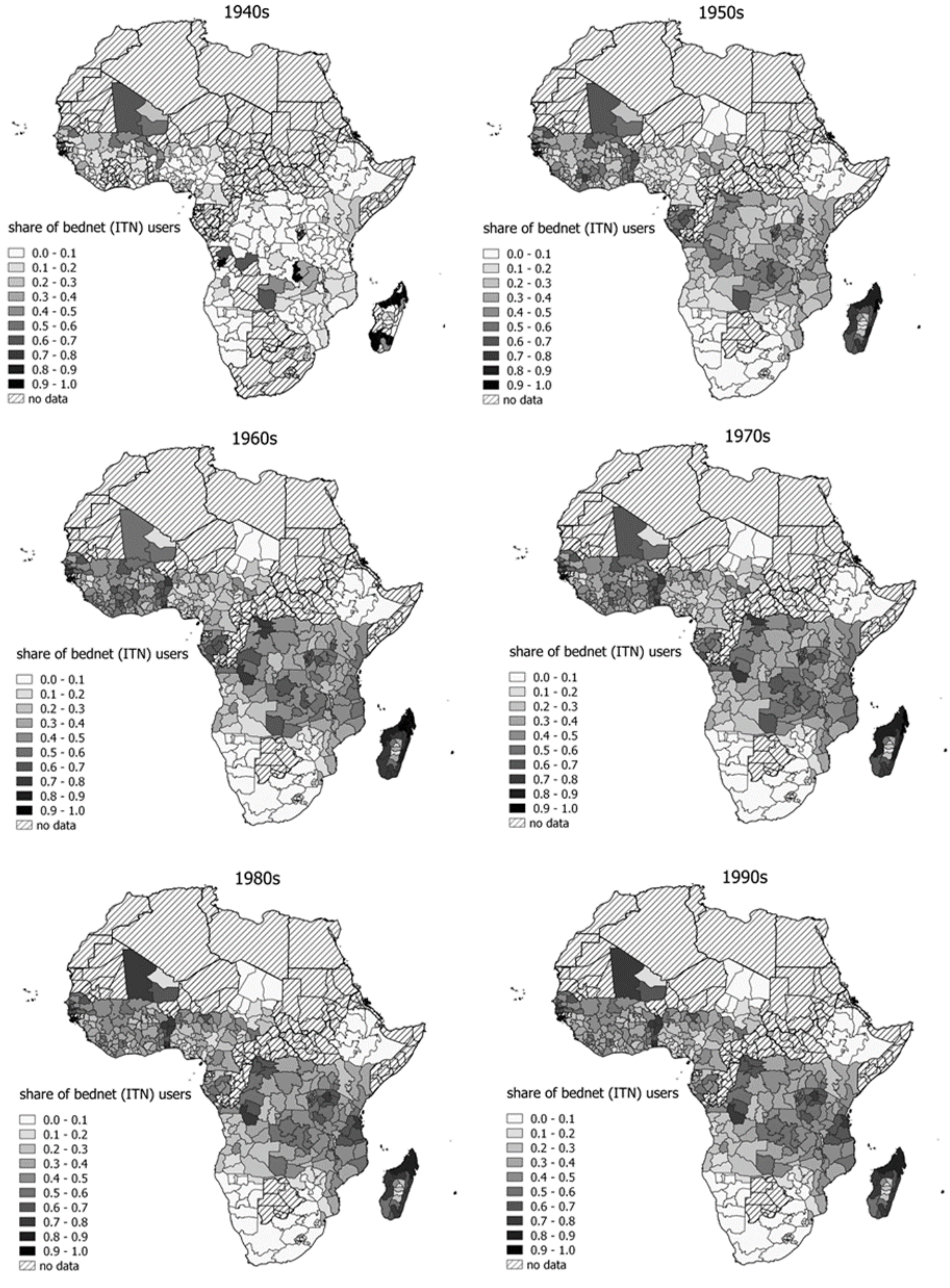


Figure D.9: Prevention and treatment-seeking behavior (intake of antimalarial drugs) for the birth cohorts at the sub-national level

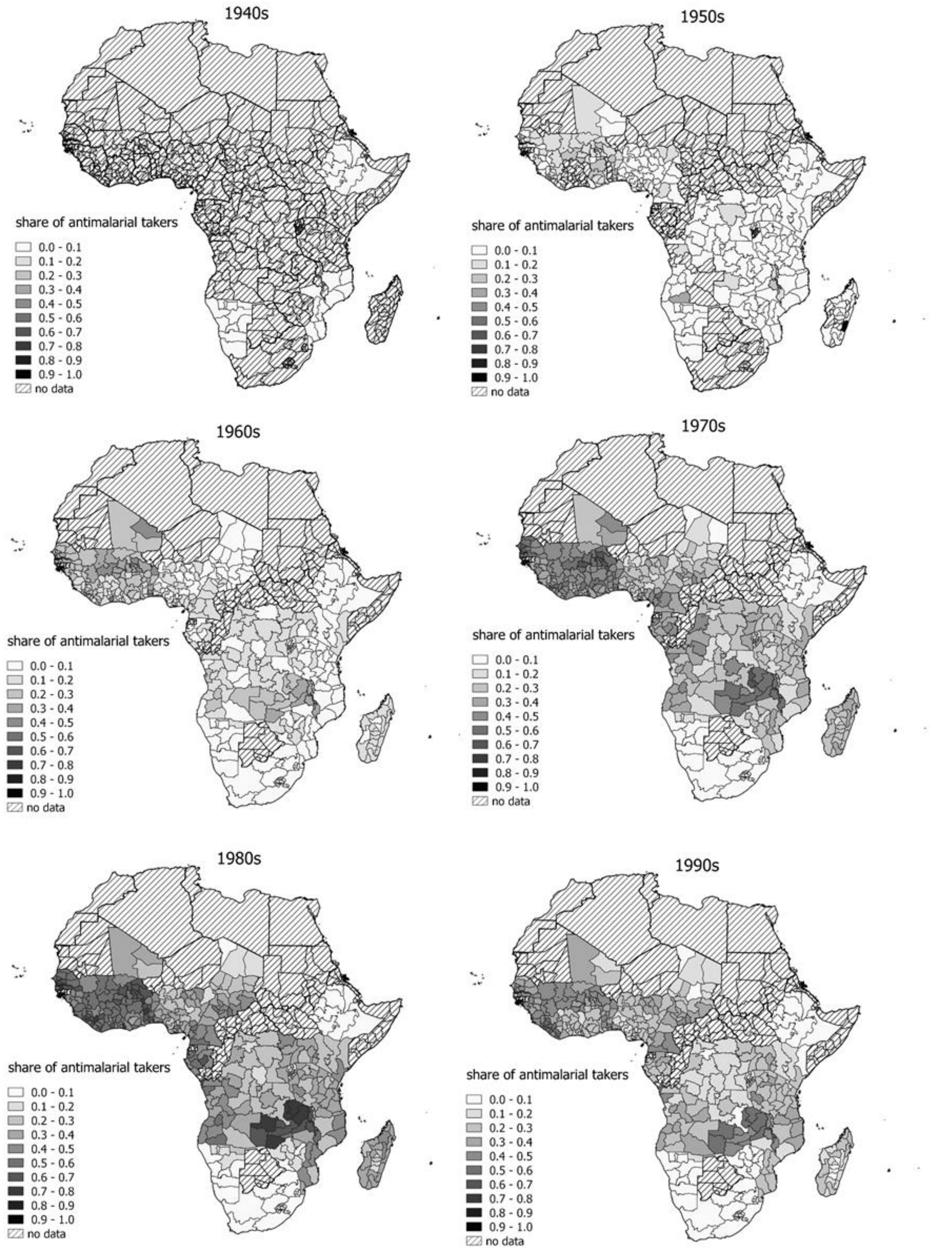
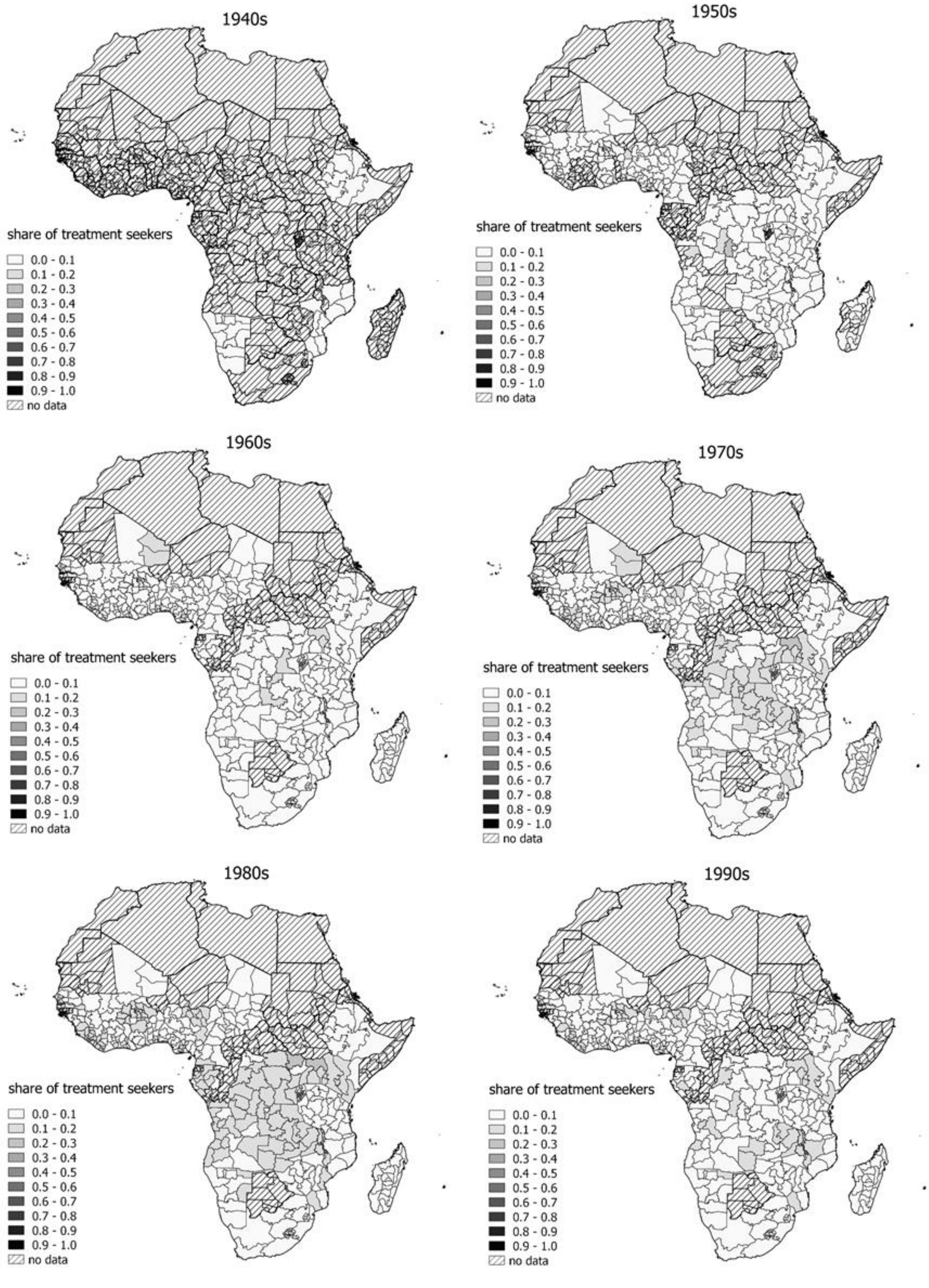
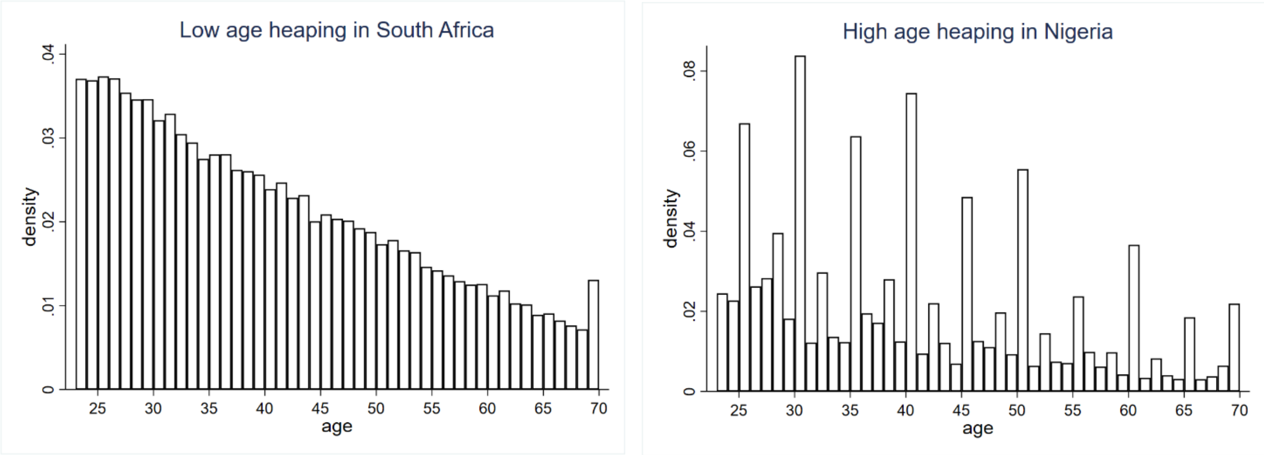


Figure D.10: Prevention and treatment-seeking behavior (medical treatment) for the birth cohorts at the sub-national level



D.11.3. Age heaping patterns

Figure D.11: Countries with low and high degrees of age heaping



D.11.4. Numeracy and literacy

Figure D.12: Correlation between treatment-seeking behavior and human capital variables

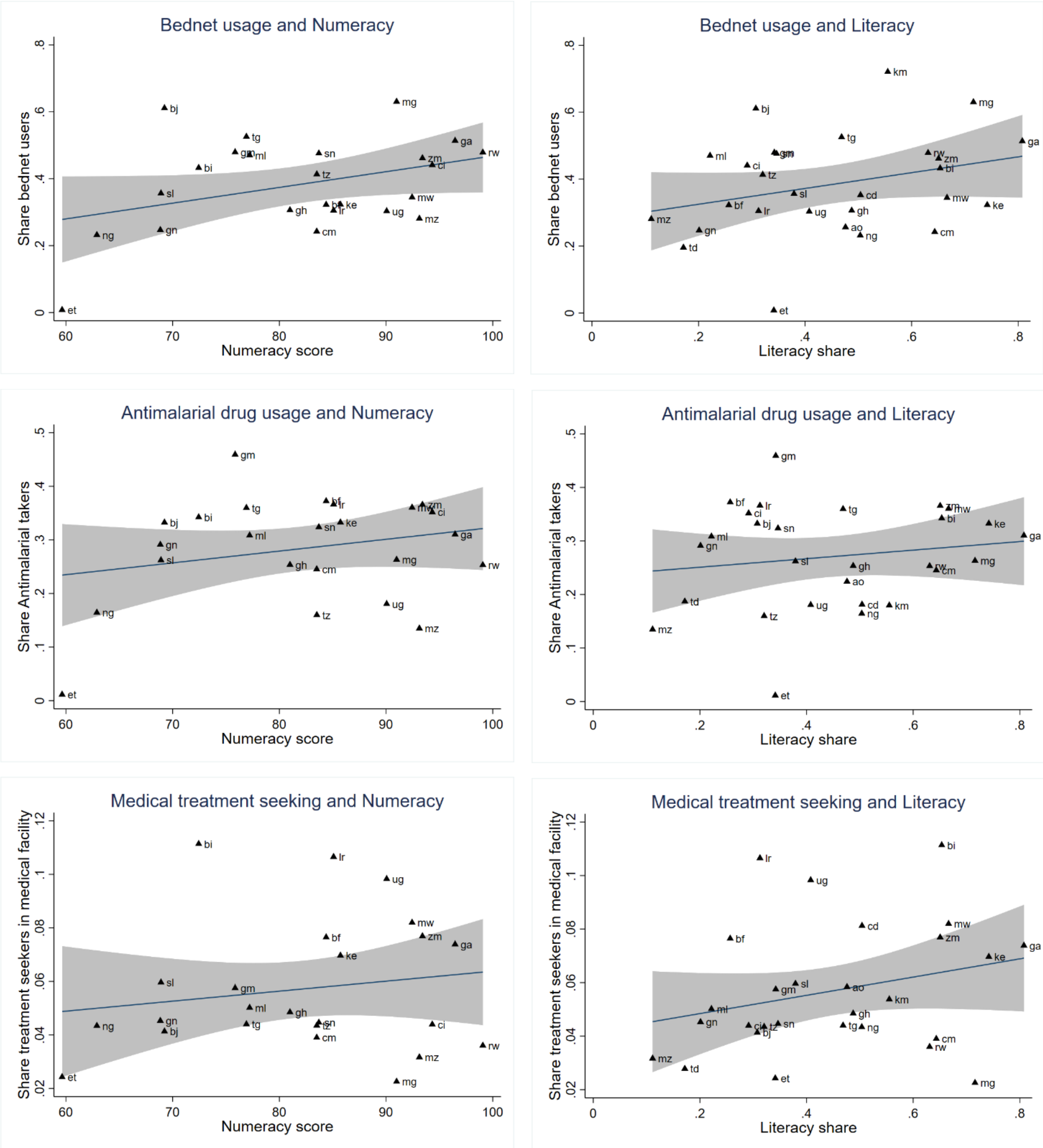
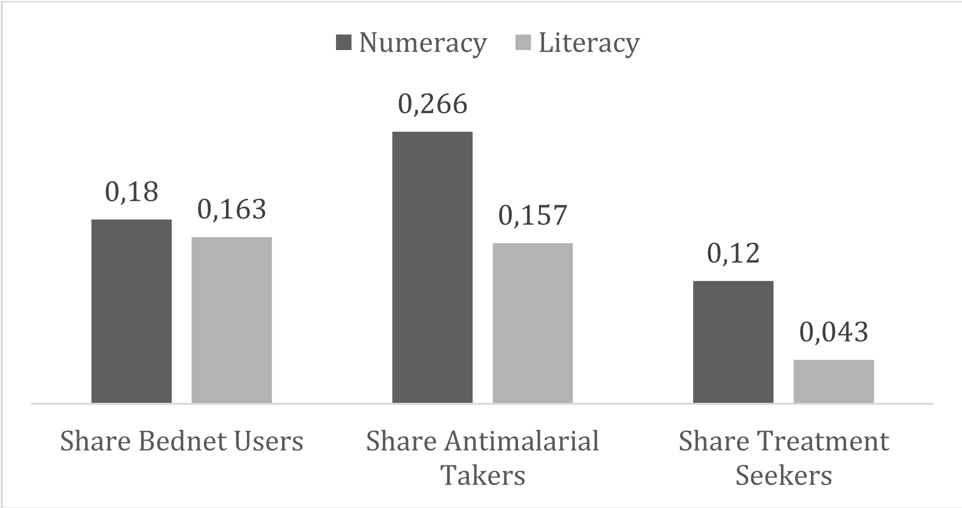


Figure D.13: Correlation coefficients between numeracy and literacy



E. Summary and Outlook

This dissertation sheds light on key aspects of long-term socio-economic progress in sub-Saharan Africa. More precisely, it is devoted to the relationship between education, gender inequality, health, and economic development. Accordingly, the three chapters of this thesis address the following research questions: To what extent did sub-Saharan Africa's 20th century schooling revolution benefit boys and girls equally? What were the patterns and determinants of gender inequality in education? Is sub-Saharan Africa's economic development path dependent on these educational gender disparities? And what role does education, in particular, numeracy and literacy play in health, notably in malaria prevention and treatment-seeking behavior?

The first chapter investigates the evolution and correlates of gender inequality in education across sub-Saharan Africa covering most of the 20th century. While empirical studies have investigated long-term trajectories and determinants of educational gender differences in Europe and the US (Goldin et al. 2006; Becker and Woessman 2008; Bertocchi and Bozzano 2016; Baten et al. 2017), Latin America (Duryea et al. 2007; Manzel and Baten 2009), and Asia (Friesen et al. 2012), this study focuses on sub-Saharan Africa, a gap that needs to be filled. It analyzes the evolution of gender differences in education at three levels of aggregation: world region, country, and district. Comparing the evolution of Africa's educational gender gap patterns with the trajectories of other world regions including South Asia, Southeast Asia, and the Middle East, which all experienced significant educational expansion during the 20th century, sub-Saharan Africa started out with the smallest gaps in the beginning of the century. Gender disparities increased in all world regions during the colonial era, peaking mid-century and then saw a subsequent decline. However, in sub-Saharan Africa, the gender gaps closed much slower and by the 1980s it had become the most gender unequal region in terms of educational provision. Linking these gender differences in education to male educational expansion, an inverted-U relationship, the *educational gender Kuznets curve* can be observed, showing an initial increase in educational gender inequality followed by a decrease as male education expanded. Comparing long-term trajectories of educational gender differences across 21 African countries, findings show substantial cross-country heterogeneity within Africa during the 20th century. In former French colonies, educational expansion was slow and linked to higher and more persistent gender disparities as compared to former British colonies where the convergence of educational provision for men and women started earlier. Most African countries, although peaking at different levels and decades, followed the educational gender Kuznets curve pattern. In Southern African countries, however, women achieved better educational outcomes over the entire period analyzed, which can be associated with the absenteeism of men who were in charge of cattle herding or migrated to work in the mining industry. Finally, using decadal birth cohorts, this study explores correlates of educational gender disparities for the early (1920-1939), late (1940-1959), and postcolonial (1960-1979) periods at the sub-national level. Districts with large cities, coastal location, and access to railroads witnessed smaller educational gender gaps, supporting the view that openness mattered for educational gender equality. Similarly, districts, where intense missionary activities took place, had significantly lower gender disparities in schooling.

The second chapter of this thesis is devoted to a persistence study, analyzing the relationship between educational gender disparities during the 20^{th} century and current economic development in sub-Saharan Africa. Human capital accumulation is persistent through time and transmitted across generations in a path-dependent fashion. Hence, the long-standing gender gaps in education may explain at least part of sub-Saharan Africa's poor and erratic growth performance. To the best of my knowledge, this study is the first to investigate the link between historical gender gaps in education and contemporary economic outcomes in sub-Saharan Africa at the sub-national level, using nighttime light data as a proxy for economic development. In contrast to previous research assessing the influence of educational gender inequality on economic performance, this study applies a birth cohort approach and a repeated cross-sectional design. This allows to analyze gender disparities for as early as 20^{th} century birth cohorts and thus to examine whether current economic performance in sub-Saharan Africa is path-dependent on educational gender gaps of the past century. Findings support the view of many persistence studies in the literature, namely that history matters for contemporary socio-economic outcomes (e.g., Acemoglu et al. 2002; Nunn 2008; Alsan and Wanamaker 2018; Lowes and Montero 2021). They show a strong negative association between educational gender inequality and economic outcomes. Investigating indirect effects, the results of the mediation analysis suggest that part of this negative correlation is mediated through fertility. Moreover, sub-Saharan African countries would very likely have benefited from higher investment in female education, in terms of increased GDP per capita.

The third and final chapter of this dissertation explores the role of education, in particular numeracy and literacy, in malaria prevention and treatment-seeking behavior adopted among the African population. While previous research has investigated malaria control behavior in individual countries or regions, this study exploits large survey data from the Demographic and Health Surveys as well as from the Malaria Indicator Surveys for 33 African countries divided into 408 regions. It contributes to the existing literature by providing a holistic and detailed view on the evolution of malaria prevention and treatment-seeking behavior in sub-Saharan Africa across six birth cohorts including the 1940s to 1990s. In addition, while the link between educational attainment, literacy, and malaria prevention has been studied (e.g., Fawole and Onadeko 2001; Dike et al. 2006; Castro-Sánchez et al. 2016), the role of numeracy in this aspect has not been assessed yet, a gap which this study fills. Findings reveal that being numerate as well as being literate is positively correlated with the usage of insecticide-treated bednets (ITN's), the intake of antimalarial drugs, and the seeking of treatment in a medical facility when having malaria symptoms. Standardized coefficients suggest that numeracy skills are at least as important as literacy skills. Keeping in mind that behavioral aspects are influenced by unobservables that cannot be controlled for, this study takes into account the most important factors such as gender, socio-economic status, topology, and urban-rural setting. Results show that an increase in the share of women involved in healthcare decision-making and media exposure as well as urban sites are positively related to malaria control. On the contrary, a low socio-economic status, areas of higher altitude, and low rainfall are negatively associated with malaria prevention and treatment-seeking.

Together, the three chapters of this dissertation are an important first step in explaining the complex interrelationship between education, gender inequality, health, and economic progress in sub-Saharan Africa. The findings of all studies indicate that education can create opportunities for better health and notably matters for the adaption of proper and effective malaria prevention and treatment. Beyond that, there is no doubt that human capital contributes positively to better economic performance (e.g., Mincer 1974, 1984; Lee and Lee 1995; Barro 1991, 2001; Pelinescu 2015). However, results of the second chapter show that gender disparities in education have been acting as a barrier to economic progress whereas investment in female education is likely to generate economic benefits. Although huge advances have been made in achieving gender parity in education, sub-Saharan African countries lack behind in closing gender gaps in both primary and secondary schooling (Roser and Ortiz-Ospina 2016; UNESCO 2020). Exploring whether these educational gender differences are of dynamic or structural origin is of utmost importance since different policy responses are required. Finally, while increased investment in overall education primarily provides a solution for tackling dynamic gender disparities, as shown by the educational gender Kuznets curve patterns, practicable steps that could be taken to resolve structural gaps include the understanding and addressing of prevailing regional specific biases that hinder girls and women from accessing education. Potentially, some of the findings brought forth by this thesis, can serve as an inspiration for tackling the roots and causes of gender gaps in schooling, promoting numeracy and literacy skills and, in this way contribute to improved development outcomes in sub-Saharan Africa.

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