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IZA DP No. 15966

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ABSTRACT

The Fertility Transition in Sub-Saharan Africa: The Role of Structural Change*

Despite the recent economic growth in many countries on the African continent, the region has seen a slow fertility transition. In this study, we explore whether the lack of structural economic change can explain this slow fertility transition. We create a unique panel data set combining Demographic and Health Surveys, Household Income Surveys, and nighttime light intensity data, as an indicator for industrialization, from 57 countries at the sub-national regional level over three decades to analyze the driving forces of fertility transitions across low- and middle-income countries. Our results confirm that household wealth, reduced child mortality, and female basic education are crucial for fertility reductions. Yet, our analysis also highlights the important role of increased female labor force participation in the formal sector, industrialization, increased female secondary education, and the expansion of health insurance coverage. Urbanization appears to have a limited, if any, effect. Our simulations indicate that if high-fertility countries in sub-Saharan Africa had experienced similar structural economic change as low- and middle-income countries with low fertility, their fertility levels could be up to 50% lower.

JEL Classification: D13, J11, J13, J22, O12

Keywords: demographic transition, fertility, structural change, human capital, sub-Saharan Africa

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Introduction

Whereas the global fertility rate fell from around five live births per woman in 1950 to 2.5 births in 2015, fertility rates in most countries in sub-Saharan Africa are still higher than four children per woman (United Nations DESA, 2020). Aside from South Africa and Mauritius, no other sub-Saharan African countries have completed the fertility transition, but even in these two countries fertility varies greatly across socio-economic groups (Bruni, Rigolini and Troiano, 2016). While some countries have not even started their transition, others have seen first declines in fertility, but often these declines have not been lasting and ended in some cases in so called fertility stalls (Bongaarts, 2008; Garenne, 2008; Schoumaker, 2009, 2019; Grimm et al., 2022).[1]

Since most African countries have, however, experienced a significant increase in life expectancy thanks to substantial declines in child mortality, population growth rates are at very high levels – much higher than what most other countries experienced during their demographic transitions (Lee, 2003). The under-five mortality rate in sub-Saharan Africa declined from 151 deaths per 1,000 live births in 2000 to less than 76 deaths per 1,000 live births in 2019.[2] This trend represents, by historical standards, a very rapid and sharp decline in child mortality.

High levels of fertility persist despite relatively sustained economic growth and poverty reduction in most parts of sub-Saharan Africa. On average, since the early 2000's, GDP per capita has increased in sub-Saharan Africa by about 3% on an annual basis (Rodrik, 2018). The poverty headcount index declined from 59.4% in 1999 to about 40.2% in 2018 (World Bank, 2020). In some countries, such as Côte d'Ivoire, Ethiopia, and Tanzania, per capita growth has even exceeded 7% annually in the recent past.

In most other countries of the world, sustained rates of income growth and mortality reductions have been accompanied by significant declines in fertility. Jones and Tertilt (2006), for example, show that in the US the average number of children ever born per woman declined between 1850 and 1950 from about 5.5 to 2.1 while average occupational income multiplied by eight. In East Asia and Southeast Asia, birth rates fell by about 45% and 20%, respectively, between 1960 and 1980 while labor force participation substantially increased. Bloom and Williamson (1998) show that fertility declines and labor force participation mutually reinforced each other. In Brazil, the total fertility rate fell from 6.3 in 1960 to 2.0 in 2005. This timespan included several periods of rapid economic growth. Potter, Schmertmann and Cavenaghi (2002) find a strong and consistent relationship between declines in fertility and economic growth.

Yet, the growth trajectories of countries in Asia, Europe and the Americas were quite different from what has been observed so far on the African continent. In the former, economic growth came along with substantial structural change, i.e., a massive migration of labor from agriculture to industry, especially manufacturing, whereas in the latter, it has been largely based on an extension of agriculture, natural resource extraction, and the informal sector (McMillan and Harttgen, 2014; de Vries, Timmer and de Vries, 2015; Diao, Harttgen and McMillan, 2017; Rodrik, 2018). In non-African countries, this shift in the labor composition implied increasing returns to higher education, a constant need to adapt to new technologies, increasing labor market opportunities for women, and diminishing returns to child labor. Moreover, industrialization was typically also accompanied by a formalization of the economy and hence, increased social protection, including old-age security and health insurance. In a Beckerian

[1] A fertility stall occurs when the fertility transition has (temporarily) stopped or at least markedly slowed down. Schoumaker (2009), for example, operationalizes this concept by considering two consecutive surveys. If in the more recent survey the TFR is at least as high as in the previous survey a country or region is said to have experienced a fertility stall.

[2] https://data.worldbank.org/indicator/SH.DYN.MORT?end=2019&locations=ZG&start=2000.

fertility demand framework, such shifts from agriculture to industry are sought to reduce the returns to the quantity of children and increase the returns to quality, i.e., parents tend to have fewer, but better educated children (Becker and Lewis, 1973; Becker, 1981). Hence, if economic development arises without such structural change, this substitution may not take place and parents may continue to have many children.

In this paper, we analyze to what extent the slower fertility transition in sub-Saharan Africa might be explained by slow structural economic change. Other authors have argued that the above-average level of fertility in many sub-Saharan African countries after controlling for economic development is due to a pronatalist culture (see e.g., Bongaarts, 2017; Casterline and Agyei-Mensah, 2017) and a lack of leadership that supports family planning (May, 2017). We focus on a different factor by exploring whether this slower demographic transition is also driven by a different form of economic development. We define structural change as a shift from labor out of agriculture into modern services, industry, and especially manufacturing. It comes with higher female labor market participation and higher education levels among women to fill positions in these new sectors. It is also accompanied by a higher formalization of the economy and the emergence of social security, such as health insurance and old-age security. Once such a process sets in, the two forces – structural change and reduced fertility – are likely to reinforce each other, i.e., reduced fertility itself becomes a major force of economic growth through a changing population age composition (see e.g., Bloom and Williamson, 1998; Bloom et al., 2009; Bloom, Kuhn and Prettner, 2017; Karra, Canning and Wilde, 2017). Yet, we think that structural change, in addition to reductions in child mortality and economic growth, is needed in the first place to set a fertility decline in motion.

We use a novel dataset covering 57 low- and middle-income countries over the period between 1986 and 2019 that we constructed by merging Demographic and Health Surveys and Living Standard Measurement Surveys (or analog), enriched with data on global nighttime lights, which, as we argue below, are a good proxy for industrialization and formal sector growth. We merge these data at the first level of administrative units (regions), which provides us with a regional (albeit unbalanced) panel for 524 regions from 57 countries over a period of 34 years. We use this data to test whether there is a significant relationship between the fertility transition and the degree of structural change, while taking into account a range of related indicators of more general economic development, such as child mortality, urbanization, household wealth, and basic education, which have been the focus of previous literature on fertility reductions (see e.g., Bongaarts, 2017). Of course, changes in these economic variables might also be driven by structural change; but could also occur without structural economic change. While our focus is on understanding the fertility transition in Africa, including non-African countries in the analysis gives us more variation for the analysis and allows us to explore the link between structural change and fertility at levels of structural change that so far only a few countries in sub-Saharan Africa have reached. To our knowledge, our study is the first to look at the link between fertility and structural change in low- and middle-income countries at the sub-national level. This level of disaggregation allows a more precise identification of relevant channels, which typically get blurred when country averages are used.

This paper contributes to different strands of the literature. First, it adds to the general debate about the fertility transition in sub-Saharan Africa. Recent influential research includes for example Bongaarts (2017), who stresses that, even controlling for socio-economic development in terms of mortality, income per capita, urbanization, and education, African countries still have higher fertility rates on average than other low- and middle-income countries. Casterline and Agyei-Mensah (2017) and Hertrich (2017) focus on the role of intermediate factors that stand between more general socio-economic forces and fertility decisions, such as fertility desires. Singh, Bankole and Darroch (2017) argue that although desired fertility is high in sub-Saharan Africa, it is still significantly exceeded by actual fertility, so that there is scope to reduce fertility to some extent by promoting family planning (see also Cohen, 1998; Bongaarts, 2010; Bongaarts and Casterline, 2013; Günther and Harttgen, 2016; Bloom, Kuhn and Prettner, 2017; May, 2017; Tsui, Brown and Li, 2017; De Silva and Tenreyro, 2020; Liu and Raftery, 2020). Other authors have pointed to the importance of cultural and social norms and interdependent preferences for the fertility transition (McQuillan, 2004; Fernández and Fogli, 2006; Munshi and Myaux, 2006; Canning et al., 2013; Daudin, Franck and Rapoport, 2016). In addition, this paper also contributes to a series of papers that focus specifically on 'fertility stalls' in sub-Saharan Africa (Bongaarts, 2006; 2008; Shapiro and Gebreselassi, 2008; Garenne, 2008; 2011; Ezeh, Mberu and Emina, 2009; Shoumaker, 2009, 2019; Goujon, Lutz and Samir, 2015; Grimm et al., 2022).

Our analysis also provides an empirical basis regarding the relevance of unified growth models in the African context, as we focus on some of the key drivers discussed in the literature (Galor and Weil, 1996; 2000; Galor and Moav, 2002; Doepke, 2004; Cervellati and Sunde, 2005; Strulik and Weisdorf, 2008; Galor, 2011). Unified growth theory emphasizes the increasing role of human capital and technological progress in the production process that enhances the demographic transition. Notable empirical contributions include Murtin (2013) and Chatterjee and Vogl (2018), who both identify education as the main driver of the fertility transition; the former stressing the role of increased education among the adult population and the latter stressing the role of increased investment in children's education. Finally, we contribute to the literature on structural change on the African continent by documenting that it is evolving differently as compared to other regions in the world, not to mention very heterogenous even within countries. Influential research on structural change in sub-Saharan Africa includes McMillan and Harttgen (2014), de Vries, Timmer and de Vries (2015), Barret et al. (2017), Diao, Harttgen and McMillan (2017), Rodrik (2018), and Diao, McMillan and Rodrik (2019).

The remainder of this paper is structured as follows. In Section 2, we present our dataset, introduce our key variables, and show some basic descriptive statistics. In Section 3, we lay out our empirical specifications. In Section 4, we discuss our results. In Section 5, we conclude.

Data

Data sources and merging

We created a novel dataset by combining 281 Demographic and Health Surveys (DHS) from 57 countries over a time period of 34 years (1986-2019) with several other data sources.[3] DHS include individual- and household-level information with respect to fertility, demographics, health, education, occupation, and other socio-economic characteristics. The questionnaires of DHS are largely harmonized across countries and survey years with respect to the key variables of interest, allowing us to construct consistent measures across time and space. We enrich this dataset by adding information on nighttime light intensity. Specifically, we use a harmonized annual time series on global nighttime light intensity based on weather satellite recordings covering the period between 1992 and 2018 constructed by Li et al. (2020). We explain below why we think nighttime light intensity is an adequate and useful proxy of industrialization and formal sector growth at the local level. Finally, we merge information on wages drawn from Living Standard Measurement Surveys (LSMS) and similar surveys into this dataset.

Before merging, all data was aggregated at the regional level (first-level administrative units) in each survey year. A substantial share of the sampled countries experienced changes with

[3] Section A in the Online Appendix provides an overview of all included DHS by country and year. We excluded countries from Eastern Europe and from the former Soviet Union, i.e., Albania, Armenia, and Kyrgyzstan, as their political and demographic transition in the 20th century was fundamentally different compared to countries from other world regions.

respect to regional administrative boundaries during the study period, mostly in the form of a region being split into two or more smaller regions. These administrative changes do not present a problem for an analysis based on pooled observations; however, fixed effects estimations require consistent boundaries over time. Therefore, we adjusted the region variable following the dual objective of ensuring boundary consistency over time and maximizing the number of regions included in the dataset (see Section B in the Online Appendix).

The merged dataset is a regional, unbalanced panel covering 524 regions stemming from 57 low- and middle-income countries over a 34-year period (1986-2019), providing 2,387 region-by-year observations.

Fertility: measurement and trends

The main outcome variable of interest is the total fertility rate (TFR). The TFR is derived by calculating the average number of births a woman would have during her reproductive age (15 to 49 years) if she had experienced the age-specific fertility rates observed in a specific year.[4] Instead of country means, we use survey-year-specific regional means of the TFR to explore the relationship between the advancement of the fertility transition and the degree of structural change.[5] This within-country heterogeneity is typically ignored in macro-economic country-level studies, which may blur the relationship between fertility and structural change. Figure 1 below demonstrates that indeed most countries show quite strong heterogeneity with respect to the TFR across administrative regions.

[please insert Figure 1 about here]

Child mortality, urbanization, household wealth, and basic education

The literature highlights several factors that have contributed to fertility declines across the world. These factors typically include child mortality, urbanization, household wealth or income, and female education (e.g., Bongaarts, 2003; 2017; Bongaarts and Casterline, 2013). Our analysis also accounts for these factors. Below, we briefly explain the rationale of including each of these variables and how we measure them.

Child mortality: We measure child mortality as the number of children that died between birth and their fifth birthday per 1,000 live births in a specific region. Child mortality is commonly seen as an important driver of fertility rates since high levels of child mortality push parents towards having more children due to the higher risk of losing children before they reach adulthood. If parents are risk averse it is even possible to observe a hoarding effect, i.e., parents overcompensate as they are afraid of ending up with too few children when they are old (see e.g., Pörtner, 2001).

Urbanization: Urbanization is measured as the share of households that live in an urban area. A higher degree of urbanization is expected to decrease the demand for children due to higher living costs in cities and consequently the higher costs of raising children.

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[4] While DHS typically cover women aged 15 to 49, few DHS cover women aged 15 to 59. In these cases, the TFR was calculated based on all women in this age range. This concerns the following surveys: Cameroon 2018, Haiti 2016, Mozambique 2015, Namibia 2013.

[5] To calculate the TFR, we used the TFR2 Stata command. The TFR2 command allows to produce the official DHS total fertility rates from the micro data. It transforms the birth history data into a table of number of births and number of years of exposure. The age-specific fertility rates and TFRs are then computed applying a Poisson regression model (Schoumaker, 2012).

Household wealth: We built an asset index as a proxy for household wealth and income. The list of assets considered for this index is consistent across all years and regions.[6] While a higher income and greater wealth makes it possible to feed more children, both also allow parents to invest more in children's health and education. Becker's demand side theory assumes, for example, that the income elasticity of child quality always exceeds the income elasticity of child quantity (Becker, 1981).

Female educational attainment: Lastly, we measure female educational attainment as the share of women aged 15 to 49 in a region that have at least primary education.[7] Access to basic education can lower fertility levels by increasing female reproductive autonomy (through better knowledge about contraception) as well as by delaying marriage and the start of childbearing. Access to higher education can further increase the income of women on the labor market increasing the opportunity costs of children.

Further indicators of structural change

All of the variables described above primarily mirror the socio-economic structure of a given region and can be seen as rather general measures of economic and social development. Even if they might be driven by structural change, they can also occur without structural change: through economic growth driven by natural resource extraction and trade, increased agricultural productivity, or technological progress (and/or investments) in health and education. In the following, we discuss additional variables that we regard as particularly suited indicators of structural economic change. These include female secondary or higher education, the female occupational structure, nighttime light intensity as an indicator for industrial growth, health insurance coverage, and increased earnings opportunities of women as measured by relative female wages (in comparison to males). We could think of other dimensions of structural change that are relevant for parents' fertility decisions, such as the value added in manufacturing, but the available survey data is limited in that respect. National accounts data does typically provide additional useful information, such as sectoral value added, but in most cases, this does not exist on a disaggregated level by region. Nevertheless, we trust that our measures capture a good portion of those dimensions of structural change that are relevant for our analysis. We explicitly do not control for indicators such as nuptiality, the age at marriage, the use of contraception, or desired family size, as all these behaviors must be considered as endogenous in our framework, i.e., they are jointly determined with the level of fertility and depend, to a large extent, on the same set of variables.

Female educational attainment – disentangled: We separate female educational attainment into three categories: 'no education', 'primary education', and 'secondary or higher education'. We consider an increase in the share of women with secondary or higher education as a reflection of structural change that is relevant for parents' fertility decisions. Secondary or higher education offers the opportunity to take a job in the public sector or the private formal sector and therefore offers higher earnings opportunities, which in turn increase the time costs of women.

Female occupational structure: The female occupational structure is measured as the share of women aged 15 to 49 in a region that fall into the categories 'agriculture' (employed, self-employed), 'not working', 'non-agricultural informal jobs' (unskilled industry workers, sales,

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[6] To calculate the asset index, we used the following household characteristics: Radio, TV, motorized transport (car or motorcycle), electricity, quality of drinking water, quality of floor material, quality of sanitation.

[7] While DHS typically cover women aged 15 to 49, few DHS cover women aged 15 to 59. In these cases, female educational attainment was calculated based on all women in this age range. This concerns the following surveys: Cameroon 2018, Haiti 2016, Mozambique 2015, Namibia 2013.

services, domestic workers), and ‘non-agricultural formal jobs’ (skilled industry workers, professionals, clerical staff). We allocated the different occupations based on whether they are typically carried out in a formal or in an informal setting.[8] We consider an increase in the share of women with jobs in the non-agricultural formal sector as a reflection of structural change. Again, we assume that the higher time costs that come with such jobs may reduce fertility. Such jobs typically also offer less flexible working hours and hence are less compatible with having many children. In the regression analysis, we only include ‘non-agricultural formal jobs’ as the regressor. This means that the categories ‘agriculture’, ‘non-agricultural informal jobs’, and ‘not working’ together serve as the reference category. Hence, we measure the effect on fertility of women leaving any of the latter sectors and entering the non-agricultural formal sector.[9]

Nighttime light intensity as proxy for industrialization: In addition, we include nighttime light intensity as a proxy for industrialization and formal sector development, which are likely to increase returns to higher education and female labor force participation. For each year from 1992 to 2018, Li et al. (2020) provide a gridded dataset covering the entire globe, comprised of more than 725 million pixels sized 30x30 arc seconds, where one pixel corresponds to less than one square kilometer at the equator. Each pixel reports annual average nighttime light intensity as a number ranging from 0 to 63, with higher numbers indicating higher nighttime light intensity. In combination with a shape file of all 524 regions, we calculated the mean nighttime light intensity for each region in each year as the unweighted average of the numbers reported by all pixels within the region boundaries. Since the distribution of the obtained variable is heavily right-skewed, we apply a log-transformation before using it in regressions.

Gibson, Olivia and Boe-Gibson (2020) stress that the nighttime light intensity that is recorded by satellites in poorer countries easily captures urban activity, but misses most lights that can usually be found in rural areas because many lights available in rural areas are turned off at 1.30 a.m. when satellites take their pictures from space. In rural areas, only very bright lights, such as lights emitted from a high density of streetlamps, large car parks, and enclave mining and industrial facilities can be detected.[10] This means that nighttime light intensity is not merely a proxy for urbanization. Instead, it implies that larger-scale modern industrial and service activities are captured, but not small-scale economic activities such as traditional farming, small rural shops, and markets. In our dataset, the correlation coefficient between urbanization and nighttime light intensity (in log form) is indeed only around 0.46.[11] Moreover, Keola, Andersson, and Hall (2015) report that the elasticity of nighttime light intensity with respect to GDP is positive only for countries where the share of agriculture in GDP is less than 20%. They further show that it is even possible for agriculture’s value-added to increase without seeing any increase in the nighttime light intensity detected from space. These results further confirm that nighttime lights are well-suited for our purpose as they seem to be a good proxy for

[8] For example, if the occupation of the respondent is household work or domestic work, it is reasonable to assume that this is an informal occupation whereas if the respondent is employed or is working in the government sector, we assume that we can consider this as a formal occupation. In other cases, such a self-employment in the service sector, it is not possible to clearly differentiate between the formal and informal sector.

[9] The category ‘not working’ may also capture some income-generating activities, like subsistence agriculture or small-scale sales or services (e.g., selling food, washing cars on the street), especially given the high share of women that report ‘not working’ (see Table 2).

[10] The inability of satellites to detect small, low density, settlements is also seen in Andersson, Hall and Archila (2019); out of 147 geo-referenced cities and towns in Burkina Faso, ranging in population from 7000 to 1.6 million, 83 of these communities (the largest of which had a population of 32,000) went undetected over the entire 21 years of satellite recordings. This example shows that, especially in the African context, urbanization can happen without substantial increases in nighttime light intensity.

[11] The correlation coefficients with the asset index and household electrification rates are 0.63 and 0.62, respectively.

activities correlated with industrialization and formal sector development, i.e., structural change, and not simply capture any form of economic growth.

Health insurance coverage: We consider health insurance coverage as another important dimension of structural change that may affect fertility decisions. Health insurance allows households to reduce precautionary savings for anticipated health shocks and hence, to invest more in education. The literature suggests that it also reduces the necessity to have many children as a buffer stock of labor that could be mobilized whenever a household goes through an episode of economic hardship: health shocks are one of the major causes of households to fall into poverty in low-income countries (Xu et al., 2003; Landmann and Frölich, 2015). Raising children in rural areas is not very expensive and children can take on tasks quite early in life. They can, for instance, engage in herding, cooking, cleaning, or taking care of their younger siblings (Walters and O'Connell, 1988). By engaging in household chores, they can also free up the time of other household members who can then offer their labor on others' farms or in the non-agricultural sector. To account for access to health insurance, we use the share of households in a specific region that are covered by a health insurance scheme. Health insurance coverage includes Community Based Health Insurance (CBHI), public health insurance schemes, and private insurance including those offered by private formal and public employers. We obtain this information directly from the DHS, yet it is only included in surveys from 2005 onwards. For this reason, we can analyze the effects of health insurance coverage only with smaller samples.

Data on other insurance types is scarce, but we believe that coverage by other types of insurance, including life, accident, and old-age insurance is often correlated with health insurance coverage as economies formalize. In particular old-age insurance should also reduce fertility as parents become less dependent on the support of (many) children when they age (see e.g., Bau, 2021).

Relative female wages: Lastly, we consider relative female wages to be a relevant aspect of structural change. Specifically, an increase in female wages relative to male wages may be a sign of the emergence of higher productivity employment and hence higher earnings opportunities for women. These will again imply an increase in the opportunity costs of women's time and hence potentially the cost of having children. We use the log of the average monthly female wage in a region while controlling for the log of the average monthly male wage. As the DHS do not contain wage data, we rely on the LSMS to create these variables.[12] The number of available LSMS is much smaller than the number of DHS, not all LSMS can be matched to a DHS (due to differences in regional boundaries or survey years), and not all LSMS contain (suitable) wage data.[13] Consequently, the analysis of relative female wages will also be carried out for smaller samples and is more explorative in nature.

A description of the sample

Our dataset contains a total of 2,387 region-by-year observations. To our knowledge, no other study on fertility in low- and middle-income countries has used a sub-national dataset covering such a large number of countries over such a long time horizon. As explained above, not all variables are available in all countries and in all years. To address these gaps and to ease the interpretation of our findings, we constructed three different samples. Sample 1a contains all observations that have non-missing data on the regional TFR, child mortality, urbanization, household wealth, female educational attainment, female occupational structure, and nighttime

[12] To increase comparability, we calculate mean wages based only on wages of persons aged between 15 and 59 in dependent employment, that live in urban areas, and work at least 20 hours in non-agricultural jobs.
[13] Section A in the Online Appendix provides an overview of all included LSMS by country and year.

light intensity, leading to 1,952 observations stemming from 56 countries. Sample 2a contains all observations that have in addition non-missing data on health insurance coverage, leading to 767 observations. Sample 3a contains all observations that also have non-missing data on relative female wages, leading to 259 observations. Additionally, we construct for each of these three samples subsamples 1b, 2b, and 3b, which only include observations from sub-Saharan African countries, leading to sample sizes of 1,011, 427, and 197 observations, respectively. Results for the samples including relative female wages (samples 3a and 3b) are only shown in Section D in the Online Appendix. Table 1 summarizes the composition of each sample.

[please insert Table 1 about here]

In Table 2, we provide summary statistics that illustrate the systematic differences between regions in low- and middle-income countries outside and inside of sub-Saharan Africa with regards to our variables of interest.[14] With around 5.2 children per woman, the average regional TFR in sub-Saharan Africa exceeds that of low- and middle-income countries in other regions by two children. Both the average share of women with secondary or higher education (27.8% versus 51.3%) and the average share of women working in non-agricultural formal jobs (8.6% versus 13.5%) is much lower in sub-Saharan Africa in comparison to other regions, and so is the average intensity of nighttime lights (more than a quarter lower). Health insurance coverage in sub-Saharan African regions corresponds to only a quarter of health insurance coverage of other regions. Sub-Saharan African regions also show lower household wealth and higher child mortality. Urbanization rates are more similar across samples.

[please insert Table 2 about here]

Empirical specification

To explore the link between fertility and socio-economic factors, in particular indicators of structural economic change, we regress the region- and survey-year-specific total fertility rate (TFR) on the variables introduced in Section 2 using the following specification:

$$TFR_{rct} = \rho STFR_{rct} + X'_{rct}\gamma_1 + \gamma_2(I_c \times T_t) + \varepsilon_{rct} \text{ (I)},$$

where TFR is the total fertility rate in region r and country c at time t and X is a vector containing the various explanatory variables. We first include in X only those variables that we described earlier as rather general indicators of socio-economic development, i.e., child mortality, urbanization, household wealth, and female education measured as the share of women with at least primary education. In the next step, we disentangle female education into primary education and secondary or higher education, and we add female occupation and nighttime lights as additional regressors, as well as health insurance coverage and relative female wages for smaller samples. We run these stepwise regressions both for the global samples and for the sub-Saharan Africa samples. While all regressors can arguably be linked to structural economic change, we argued in Section 2 that the second set of variables might be particularly suitable as indicators of structural economic change. The former, which have been the focus of previous literature, can however also change with economic growth in absence of structural change.

[14] Statistics for all samples are provided in Section C in the Online Appendix.

Potential omitted variable bias is mitigated in two ways. First, we control for country-specific time effects ($I \times T$). This captures national trends in fertility levels, e.g., caused by national policy or legislative changes, that otherwise might be wrongly attributed to any of the structural variables. For example, if a country abolishes child marriage, this likely has a direct effect on female education levels by allowing them to stay in school longer, and a direct effect on fertility, as later marriage is associated with delayed childbearing.

Second, we control for the spatial correlation of fertility by including the spatially lagged regional TFR, *STFR*, based on the method introduced by Kondo (2021). To do so, we first estimate a spatial weights matrix for each country using the geographical information on latitude and longitude of its regions' centroids. This matrix is then used to compute a region-specific spatially lagged variable that captures spatial dependencies across regions within a specific country. It is important to control for these spatial dependencies, as conditions that lead to high fertility levels in a given region might also affect fertility levels in nearby regions (see e.g., Canning et al., 2013).

In addition, we re-run all regressions with the following specification as a robustness check:

$$TFR_{rct} = \rho STFR_{rct} + X'_{rct}\gamma_1 + \gamma_2(I_c \times T_t) + \upsilon_{rc} + \varepsilon_{rct} \text{ (II).}$$

This specification makes full use of the panel structure of the dataset and controls additionally for region-fixed effects (υ), which allows accounting for a further sizeable portion of unobserved heterogeneity, namely all confounding factors that are constant over time for a given region. Such factors may include geographic features or very persistent cultural norms that simultaneously impact a region's level of fertility and its socio-economic development.

However, the first specification remains our preferred specification and we use the specification with region-fixed effects as a robustness check in Section E in the Online Appendix. The reason is that, depending on the samples, we have a non-negligible portion of regions with only one observation, and a substantial portion with only two observations. Regions with one observation do not enter the region-fixed effects estimations, which means we lose power and may get biased estimates. Regions with two observations also provide only limited variation for a within-estimator.

While we are confident that our identification strategy reduces the problem of omitted variable bias quite substantially, we cannot fully rule out any bias due to reverse causality. This issue is a particular concern for the variables measuring female educational attainment and female labor force participation which might be influenced by changes in fertility. Yet, the fact that we aggregate all data at the region-year level instead of working with individual-level information also reduces this problem to a large extent.

Results

Main results

This section presents our results regarding the relationship between the regional TFR and standard measures of economic development as used in previous literature as well as with more specific indicators of structural economic change. Table 3 shows the corresponding regressions. The first three columns refer to regressions using the global samples and the last three columns to regressions using the sub-Saharan Africa samples. Columns (1) and (4) present the results from regressions with the basic set of regressors, Columns (2) and (5) correspond to regressions with the full set of structural variables, and Columns (3) and (6) additionally include health insurance coverage (but for smaller samples). All shown results are based on the model without controlling for region-fixed effects. The results from the regressions with relative female wages are shown in Section D and those with region-fixed effects in Section E in the Online Appendix.

[please insert Table 3 about here]

Child mortality, urbanization, household wealth, and female education

The coefficient of child mortality is positive, sizeable, and statistically significant. The results suggest that a decrease in the child mortality rate by 100 deaths per 1,000 live births is associated with a decrease in the TFR by around 0.4 children in the global sample and around 0.3 children in the sub-Saharan Africa sample (Columns (1) and (4), Table 3). Our results hint to a rather weak relationship between urbanization and fertility. Coefficients are small, statistically insignificant at conventional levels, and even switch signs across samples and specifications.

Our analysis consistently shows large, negative, and statistically significant coefficients associated with household wealth, which we measure using an asset index. The coefficient suggests a decrease in the TFR by around 0.7 children associated with a one standard deviation increase in the asset index in the global sample and around 0.6 children in the sub-Saharan Africa sample. Finally, the regressions suggest a significant negative relationship between access to education for women and fertility. An increase in the share of women with at least primary education by ten percentage points is associated with a decrease in the TFR by about 0.15 children (0.19 children in sub-Saharan Africa). All results remain similar in magnitude and statistically significant when controlling for region-fixed effects (see Section E in the Online Appendix).

These results are consistent with findings from cross-country regressions in the literature. Bongaarts (2017), for example, uses a sample of 71 low- and middle-income countries and finds a significant negative effect associated with GDP per capita and the population share with primary education, a negative effect (though not significant) with life expectancy, and no effect associated with urbanization.

Further indicators of structural change

Female educational attainment – disentangled: An interesting question is whether the above-described effects associated with female educational attainment are driven by primary education or by secondary or higher education. The estimates in Columns (2) and (5) of Table 3 suggest a similarly important role of both education levels. For a ten percentage points increase in women's attainment in the respective education levels, the estimated effect sizes imply a reduction in fertility by about 0.13 to 0.15 children in the global sample and around 0.18 in the sub-Saharan Africa sample. If, alternatively, we use the specification with region-fixed effects, we find that the coefficient associated with primary education is reduced by half and loses its significance, while the coefficient for secondary or higher education increases markedly and remains significant (see Section E in the Online Appendix).

Female occupational structure: The share of women working in non-agricultural formal jobs is negatively associated with fertility. While the effect is statistically insignificant in the global sample, it is much larger and statistically significant in the sub-Saharan Africa sample. The latter coefficient implies a decrease in the TFR by 0.24 children if the share of women in non-agricultural formal jobs increases by ten percentage points (Column (5), Table 3). This is quite a sizable effect, yet it is not robust to the inclusion of region-fixed effects, probably due to the limited within-variation conditional on all other explanatory variables in the model. Overall, a shift of the female labor force towards the non-agricultural formal sector seems to matter for the fertility transition, especially in sub-Saharan Africa where non-agricultural work in the formal sector is still rare among women.

Nighttime light intensity as an indicator for industrialization: The association between nighttime light intensity and the regional TFR is negative and statistically significant in the global sample. The effect size is on the order of -0.06 children for a doubling of nighttime light intensity (Column (2), Table 3). When analyzing the sub-Saharan Africa sample, the coefficient stays negative, but loses significance and magnitude. The effect also vanishes if we include region-fixed effects. The smaller and non-significant effect in the sub-Saharan Africa samples might be due to the fact that the level and variation of nighttime lights in this region is markedly lower than in other regions. Similarly, within-variation for panel regressions is limited, as nighttime light intensity changes only slowly over time.

Health insurance coverage: Last, we discuss the effects associated with health insurance coverage. The association between health insurance coverage and fertility is negative and significant for both the global sample and the sub-Saharan Africa sample. For the global sample, a ten percentage points increase in health insurance coverage is associated with a decrease in the TFR by 0.07 children, but this effect is not robust to region-fixed effects. In sub-Saharan Africa, the effect is much larger, with a decrease in the TFR by 0.19 children and it remains statistically significant when controlling for region-fixed effects. The stronger effect measured for the sub-Saharan Africa sample might in part be due to the comparably harsh disease environment there, which makes households more vulnerable to health shocks and related financial hardship than households elsewhere.

Figure 2 provides an overview of the effect sizes that are associated with our main variables of interest. The coefficients are based on our main specification with the full list of regressors. For better comparability, all effects have been standardized by expressing them in units of their (sample-specific) standard deviation. Light grey bars indicate insignificant effects. With a reduction of around 0.63 children for a one standard deviation increase in the asset index, household wealth is the most important driver of fertility among all regressors considered. It is followed by female educational attainment, particularly secondary or higher education, with a standardized effect size of -0.33 in the global sample and -0.40 in the sub-Saharan Africa sample. A one standard deviation increase in the child mortality rate is associated with a drop in fertility by around 0.21 children. This effect is generally stable across samples. Female employment in the non-agricultural sector, a key trait of structural change, and health insurance coverage, seem to be particularly relevant in the sub-Saharan African context, with standardized effect sizes of -0.16 and -0.23, respectively. Industrialization, as proxied by nighttime light intensity further spurs the transition, even if only modestly, but we do not find any evidence that urbanization per se reduces fertility. Moreover, we find suggestive evidence that increased earnings opportunities for women as measured by higher relative female wages are also associated with lower fertility, but this correlation is based on small samples (Section D in the Online Appendix).

[please insert Figure 2 about here]

To analyze the relative importance of the various factors that we consider, we conducted a Shorrocks decomposition (Shorrocks, 1982). This method allows us to estimate the relative contribution of the different explanatory variables to the TFR's variance. We applied the decomposition to Model I with the full list of explanatory variables, i.e., Columns (2), (3), (5), and (6) from Table 3. Table 4 presents the relative contribution of each explanatory variable to the R-squared. The decomposition confirms that household wealth and child mortality are highly important factors, each contributing to around 11% of the explained variation in the TFR. Notable is the importance of female secondary or higher education in comparison to primary education, explaining another 10% of the variance in the TFR. The other variables that we assumed to be direct indicators of structural economic change (nighttime light intensity, female occupational structure, and health insurance coverage) explain together another 12-14% of the TFR. This decomposition exercise also confirms the importance of accounting for spatial dependencies and for country-specific time trends, as they contribute to around 20% and 30%, respectively, to the R-squared.

[please insert Table 4 about here]

The unlocked potential of structural change – some illustrative simulations

To illustrate how structural change can spur the fertility transition, we simulate regional fertility levels for the least advanced (in terms of the fertility transition) countries in sub-Saharan Africa under the hypothetical assumption that they had been exposed to the same degree of structural change as the most advanced regions in our sample. For this, we first identified all regions with a TFR below 2.5 in recent survey years (no older than 2010) and then selected from each available country the region with the lowest TFR.[15] This selection process led to 14 regions from 14 different countries: Bangladesh (Khulna), Cambodia (Phnom Penh), Colombia (Central), Dominican Republic (Region 3), Guatemala (Metropolitan), Haiti (Metropolitan Area/West), Honduras (Francisco Morazan), India (Sikkim), Indonesia (Yogyakarta), Jordan (Balqa/Amman/Madaba), Nepal (Far Western), Peru (Tacna), Philippines (National Capital Region), and Turkey (Central). For these 14 regions, we then computed the means for all explanatory variables included in our regression models. We then identified those countries in sub-Saharan Africa with a national TFR higher than 5 in their most recent survey year. This led to the selection of the following nine countries: Angola, Benin, Burundi, Chad, Congo, Congo DR, Mali, Niger, and Nigeria.[16] We then imputed for all regions in each of these nine countries, for the explanatory variables, the averages from the 14 regions outside sub-Saharan Africa. We did this in two alternative ways. In approach 1, we only impute the values of those variables that we argued are particularly suitable to capture structural economic change: female educational attainment, female occupational structure, and nighttime light intensity – once without and once with considering health insurance coverage. In approach 2, we additionally impute values for child mortality, urbanization, and household wealth.

Using the estimated regression coefficients from our empirical analysis for the sub-Saharan Africa sample, we then predicted the hypothetical TFR for each region in each country. For comparison, we also predicted the TFR using the actual levels in the nine sub-Saharan African countries of the explanatory variables. For the predictions, we accounted for country-specific time effects, but did not include the spatially lagged TFR. This is because we simulate the TFR for all regions in a country and the spatial lag only considers the TFR of other regions within country borders. Consequently, the spatial lag would be based on simulated values itself.

The results from this simulation are shown in Table 5 and suggest that if the regions in the nine selected lagging countries had experienced the same structural change as the 14 regions with the lowest fertility rates, their TFR would be markedly lower. In light of the remaining identification issues, the magnitude of the predicted fertility reductions should of course be interpreted with caution. Based on approach 1, the mean regional TFR is predicted to be around 5.1 (or 4.5 when health insurance coverage is also considered) instead of around 6.1. Using

[15] For the sake of generalizability, we excluded regions from Maldives despite fulfilling the selection criteria, as it is a very small island with a population of only around half a million.

[16] Burkina Faso, Mozambique and Uganda also have a TFR higher than 5 but are excluded because of incomplete data for the indicators of structural change.

approach 2, these values further decrease to a simulated mean regional TFR of only 3.9 (or 3.0). Overall, the scope of fertility reductions ranges from 15% (most conservative) to 50% (most optimistic). We believe that the true potential for fertility reduction through structural change might be closer to the optimistic scenarios as substantial improvements in, for example, female educational attainment and labor force participation in the formal sector are unlikely to come without substantial improvements in household wealth and child health. Yet, even the simulated fertility rates from the optimistic scenarios are substantially higher than the mean TFR of 2 as observed in the 14 lowest-fertility regions. These differences could stem from differences in cultural preferences and social norms to which other authors have hinted (see e.g., McQuillan, 2004; Fernández and Fogli, 2006; Munshi and Myaux, 2006; Daudin, Franck and Rapoport, 2016; Bongaarts, 2017; Casterline and Agyei-Mensah, 2017). Yet, our simulations support the hypothesis that the absence of substantial structural change accounts for a sizeable share of the high levels of fertility observed in most regions and countries in sub-Saharan Africa.

[please insert Table 5 about here]

Conclusion

Our results confirm that structural economic change is, together with child mortality, primary education, and household wealth, a key driver of the fertility transition. Secondary and higher female education, female employment in non-agricultural formal jobs, industrialization as proxied by nighttime light intensity, and health insurance coverage further spur the fertility transition. This result implies that the slow structural change in sub-Saharan Africa as documented by de Vries, Timmer and de Vries (2015), Diao, Harttgen and McMillan (2017), and Diao, McMillan and Rodrik (2019) and as also shown by our data might be a key obstacle to the fertility transition in many countries. Our simulations show that if countries in sub-Saharan Africa with the highest fertility levels had experienced similar structural change as the countries with the lowest fertility rates in our sample, their fertility levels would be up to 50% lower compared to what they are now.

While cross-sectional data used in our analysis and simulations do leave room for endogeneity, our study still makes a noteworthy contribution to the existing literature. First, we expand the list of potential drivers of fertility declines. Second, we conduct a more nuanced analysis at the sub-national regional level, controlling for country-specific time effects, which goes beyond typical cross-country analysis. Third, we test the robustness of our results by estimating each model with region-fixed effects.

Our results suggest that structural economic change could be an effective trigger for the fertility transition in sub-Saharan Africa. Once such a fertility decline sets in, it is likely to further accelerate female labor force participation and increased investment in education. Yet, we do not think that a fertility decline itself can trigger structural economic change. Moreover, family planning may help parents to achieve lower fertility goals, but we believe family planning alone is unlikely to play a decisive role in the absence of structural change, as the demand for children would remain high.

Many countries in sub-Saharan Africa have seen large reductions in child mortality rates and large increases in primary school enrollment enrolment, as well as modest increases in households' income and wealth. This has also led to some decline in fertility as much of the literature would suggest (see, e.g., Kalemli-Ozcan, 2002), but it has not been sufficient to set a fertility reduction in motion comparable to what has been seen in other regions of the world. In other region, economic development was accompanied by a large increase in secondary education, industrialization, the development of the private formal sector, and social security, all boosting the fertility decline through a fundamental change in the direct and indirect costs of children. Thinking about the type of policies that could accelerate such a structural change in sub-Saharan Africa is beyond the scope of this paper, but it may include classical industrialization policies based on strengthening for example manufacturing or agri-business. Enhanced investment in higher education could accompany this process. Finally, access to formal insurance, which reduces the need for many children, can probably further push the demographic transition.

Structural change needs to accelerate in sub-Saharan Africa to turn the demographic burden that many African countries are increasingly experiencing into a demographic gift. The demographic gift could arise if fertility rates decline and as a result, a large work force coincides with a low dependency ratio (as described in Bloom, Kuhn and Prettner (2017) and Karra, Canning and Wilde (2017)). Bloom and Williamson (1998) have shown that this has been a substantial driver of the economic miracle in emerging Asia. Fertility rates that decline substantially could further boost economic development and structural change so that the process could become self-perpetuating.

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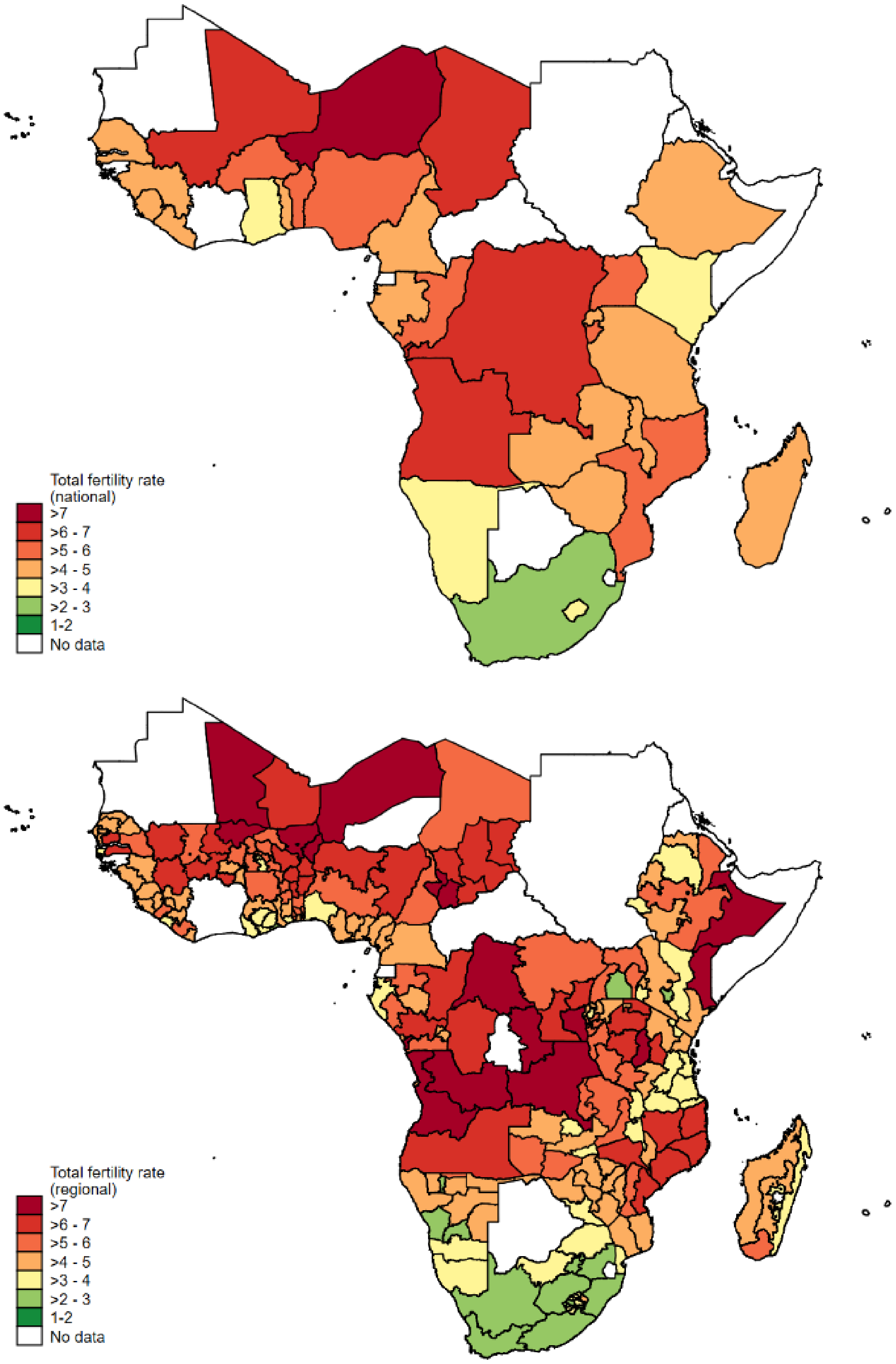
Figures and Tables

Figure 1: A comparison of national and regional total fertility rates in Sub-Saharan Africa



Note: The map on top shows the national TFR and the map below the regional TFR for the sub-Saharan African countries in our sample in the respective latest available survey year. The redder the area, the higher the TFR, the greener the area, the lower the TFR. Countries/regions without fertility data are left blank.
Source: Own calculations using data from DHS.

Table 1: Information on samples: included variables, regional coverage, and sample size

Variables in sample	**Regional and temporal coverage of samples**	
	All regions	**Sub-Saharan Africa**
TFR, child mortality, urbanization, household wealth, female educational attainment, female occupational structure, nighttime light intensity	*Sample 1a:* – 1,952 observations – 56 countries – 1992 – 2018	*Sample 1b:* – 1,011 observations – 32 countries – 1992 – 2018
TFR, child mortality, urbanization, household wealth, female educational attainment, female occupational structure, nighttime light intensity, health insurance coverage	*Sample 2a:* – 767 observations – 45 countries – 2006 – 2018	*Sample 2b:* – 427 observations – 31 countries – 2006 – 2018
TFR, child mortality, urbanization, household wealth, female educational attainment, female occupational structure, nighttime light intensity, relative female wages	*Sample 3a:* – 259 observations – 16 countries – 1993 – 2018	*Sample 3b:* – 197 observations – 11 countries – 1993 – 2018

Source: Own calculations using data from DHS, LSMS (and similar surveys) and Li et al. (2020).

Table 2: Summary statistics

	Regions outside of sub-Saharan Africa		Regions in sub-Saharan Africa	
	Obs.	Mean	Obs.	Mean
Fertility				
Regional total fertility rate (TFR)	941	3.298	1,011	5.223
Child mortality				
Child deaths (<5y.) per 1,000 live births	941	78.380	1,011	132.044
Urbanization				
Share of households located in urban area	941	0.452	1,011	0.352
Household wealth				
Weighted mean of household asset index	941	1.133	1,011	0.137
Female educational attainment				
Share of women with no education	941	0.156	1,011	0.342
Share of women with primary or higher education	941	0.844	1,011	0.658
Share of women with primary education	941	0.331	1,011	0.380
Share of women with secondary or higher education	941	0.513	1,011	0.278
Female occupational structure				
Share of women not working	941	0.473	1,011	0.358
Share of women working in agriculture	941	0.176	1,011	0.313
Share of women working in non-agricultural informal jobs	941	0.217	1,011	0.244
Share of women working in non-agricultural formal jobs	941	0.135	1,011	0.086
Industrialization				
Log of mean nighttime light intensity	941	3.677	1,011	2.636
Health insurance coverage				
Share of households with health insurance	340	0.342	427	0.082
Relative female wages				
Average male wage	62	442.494	197	429.942
Average female wage	62	290.934	197	309.248
Male to female wage ratio	62	1.607	197	1.845

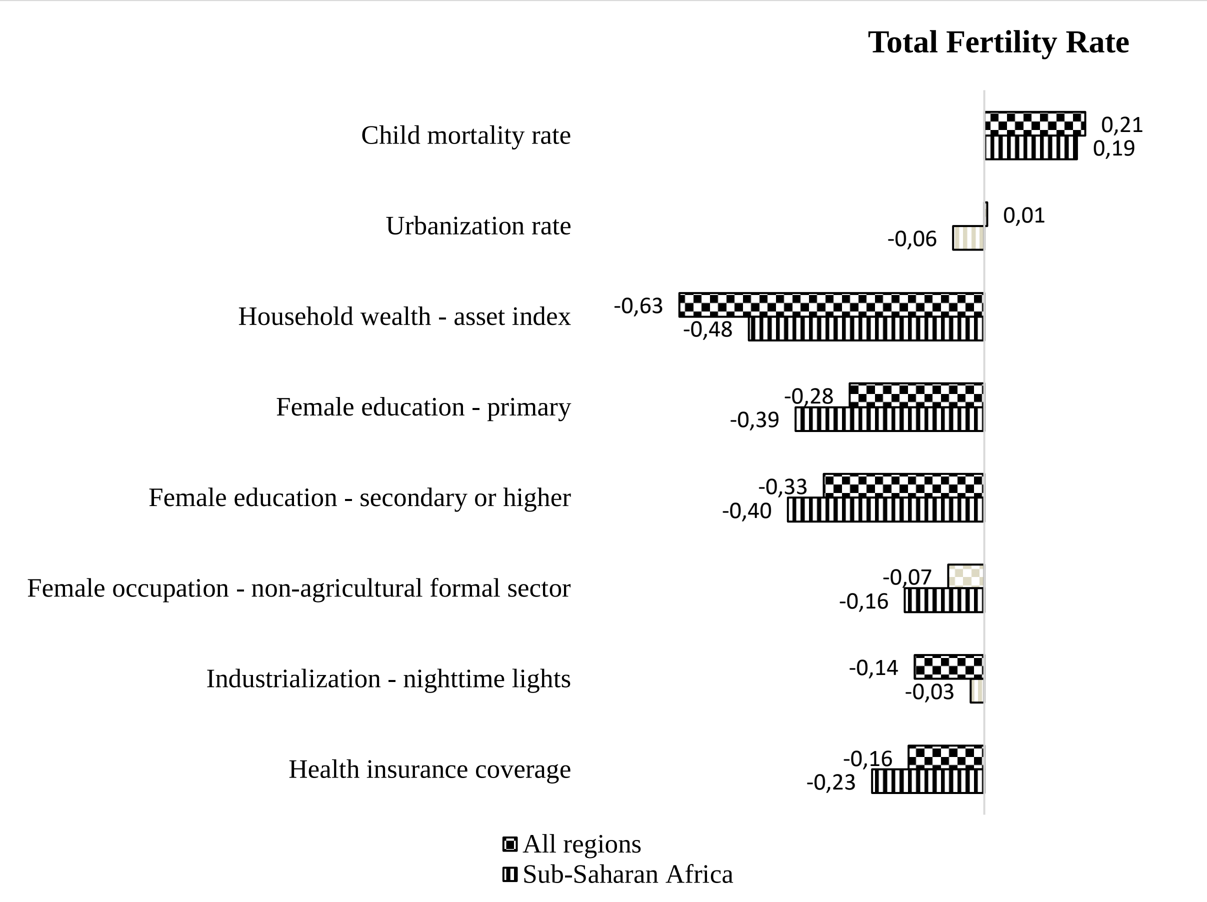
Notes: Summary statistics are calculated using the largest possible sample for each variable. Nighttime light intensity is measured on a continuous scale from 0 to 63 with higher values corresponding to higher nighttime light intensity. Wages are monthly wages in 2011 intl. $ PPP.
Source: Own calculations using data from DHS, LSMS (and similar surveys) and Li et al. (2020).

Table 3: Fertility regressions

Explanatory variables	All regions			Sub-Saharan Africa		
	(1) Sample 1a	(2) Sample 1a	(3) Sample 2a	(4) Sample 1b	(5) Sample 1b	(6) Sample 2b
Child mortality						
Child deaths (<5y.) per 1,000 live births	0.004*** (0.0012)	0.004*** (0.0010)	0.007*** (0.0013)	0.003** (0.0013)	0.003** (0.0013)	0.007*** (0.0011)
Urbanization						
Share of households located in urban area	-0.086 (0.2056)	0.022 (0.2745)	0.269 (0.2942)	-0.313 (0.3877)	-0.257 (0.4575)	-0.131 (0.3877)
Household wealth						
Weighted mean of household asset index	-0.721*** (0.0679)	-0.619*** (0.0664)	-0.664*** (0.1069)	-0.630*** (0.1028)	-0.538*** (0.0919)	-0.525*** (0.1736)
Female educational attainment						
Share of women with primary or higher education	-1.496*** (0.3948)			-1.875*** (0.4217)		
Share of women with primary education		-1.453** (0.6749)	-1.622** (0.6716)		-1.832** (0.9280)	-1.959** (0.8344)
Share of women with secondary or higher education		-1.314*** (0.4621)	-1.394*** (0.4797)		-1.805** (0.7399)	-1.695** (0.7515)
Female occupational structure						
Share of women working in non-agricultural formal jobs		-0.975 (0.6019)	-0.766 (0.6387)		-2.424** (1.0678)	-2.108 (1.2879)
Industrialization						
Log of mean nighttime light intensity		-0.063** (0.0245)	-0.086** (0.0406)		-0.012 (0.0235)	-0.020 (0.0464)
Health insurance coverage						
Share of households with health insurance			-0.670* (0.3486)			-1.878** (0.8869)
Country-specific time-effects	yes	yes	yes	yes	yes	yes
Spatial lag of TFR	yes	yes	yes	yes	yes	yes
Region-fixed effects	no	no	no	no	no	no
R-Squared	0.867	0.869	0.883	0.784	0.789	0.824
Observations	1,952	1,952	767	1,011	1,011	427
Region groups	509	509	406	259	259	239

Notes: Each column refers to one regression. Robust standard errors clustered at the country level in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.
Source: Own calculations using data from DHS and Li et al. (2020).

Figure 2: Driving forces of the fertility transition – overview of standardized effect sizes



Notes: All coefficients were obtained from regressions using Model I with the full list of covariates, but with sample-specific standardized regressors. For all variables, coefficients were obtained from regressions with the largest possible samples. Bars with checkered pattern are based on all regions, bars with vertical stripes on regions from sub-Saharan Africa. Black filling indicates significant coefficients and light-grey filling indicates insignificant coefficients (p>0.1).
Source: Own calculations using data from DHS and Li et al. (2020).

Table 4: Shorrocks decomposition: contribution of explanatory variables to the fertility transition

	All regions Sample 1a	Sub-Saharan Africa Sample 1b	All regions Sample 2a	Sub-Saharan Africa Sample 2b
Child mortality				
Child deaths (<5y.) per 1,000 live births	10.62%	10.51%	11.63%	11.59%
Urbanization				
Share of households located in urban area	4.14%	7.34%	4.03%	6.12%
Household wealth				
Weighted mean of household asset index	11.64%	10.61%	12.14%	10.12%
Female educational attainment				
Share of women with primary education	0.83%	2.09%	1.17%	2.02%
Share of women with secondary or higher education	9.43%	10.61%	10.27%	10.02%
Female occupational structure				
Share of women working in non-agricultural formal jobs	5.37%	6.95%	5.30%	8.00%
Industrialization				
Log of mean nighttime light intensity	6.16%	5.74%	3.60%	2.65%
Health insurance coverage				
Share of households with health insurance	n.a.	n.a.	4.82%	2.02%
Spatial lag of TFR	*20.82%*	*17.37%*	*19.45%*	*19.09%*
Country-specific time-effects	*31.58%*	*30.28%*	*28.07%*	*28.99%*
Total R-Squared	0.87	0.79	0.88	0.82

Note: Each column refers to one regression decomposition. All regressions are based on specification I with the full list of covariates.
Source: Own calculations using data from DHS and Li et al. (2020).

Table 5: The effect of structural change on fertility, results from simulations

Simulation results (mean values)	Simulation approach 1		Simulation approach 2	
	without health insurance coverage	*with* health insurance coverage	*without* health insurance coverage	*with* health insurance coverage
Observed TFR – w/o structural change	6.15	6.15	6.15	6.15
Predicted TFR – w/o structural change	6.12	6.12	6.12	6.12
Predicted TFR – w/ structural change	5.14	4.53	3.93	2.97
Total difference	0.99	1.59	2.19	3.15
Relative difference	0.15	0.26	0.34	0.50

Notes: Each column refers to one prediction. All predictions are based on specification I, but without consideration of spatial lags. Simulation approach 1 imputes female educational attainment, female occupation structure, and nighttime light intensity (and additionally health insurance coverage). Simulation approach 2 extends the imputations to include child mortality, urbanization, and the asset index. Line 1 contains the mean regional TFR as observed in the dataset for the nine highest-fertility countries in sub-Saharan Africa. Line 2 contains for the same nine countries the predicted mean regional TFR based on the actual values of all regressors as observed in the dataset. Line 3 contains for the same nine countries the predicted mean regional TFR based on the imputed values of the structural variables.
Source: Own calculations using data from DHS and Li et al. (2020).

Online Appendix – Supplementary Material

Not intended for print publication

Table of content

A. Overview of included DHS and LSMS/HIS surveys

Table S1 below presents an overview of all included DHS and LSMS/HIS by country and year.

Table S1: List of included DHS and LSMS/HIS, by county and year

	ca. 1992	ca. 1998	ca. 2004	ca. 2010	ca. 2016
Angola			2007	2011	2016
Bangladesh	1994	1997 2000	2004 2007	2011	2014 2018
Benin		1996	2001 2006	2012	2018
Bolivia	1989 1994	1998	**2003**	2008	
Brazil	1986	1996			
Burkina Faso	**1993**	**1999**	**2003**	**2010**	**2014** 2018
Burundi				2010 2012	2016
Cambodia		2000	2005	2010	2014
Cameroon	1991	**1998**	**2004**	2011	2018
Chad		1997	2004		2015
Colombia	1986 1990 1995	2000	**2005**	2010	2015
Comoros		1996		2012	
Congo, Dem. Rep.			2007		2014
Congo, Rep.			2005	2012	
Dominican Rep.	1986 1991	1996 1999	2002 2007		2013
Egypt, Arab Rep.	1988 1992 1995	2000	2003 2005	2008	2014
Ethiopia		2000	2005	2011	**2016**
Gabon		2000		2012	
Ghana	**1988** **1993**	**1998**	2003	**2008**	2014 2016 2019
Guatemala	1987 1995	**1999**			2015
Guinea		1999	2005	2012	2018
Guyana			2005	2009	

Haiti	1995		2000		2006		2012				2016						
Honduras					2006		2012										
India	1993		1999		2006						2015						
Indonesia	1991	1994	1997		2003	2007	2012				2017						
Jordan	1990		1997		2002	2007	2009	2012			2018						
Kenya	1989	1993	1998		2003		2009				2014	2015					
Lesotho					2004		2009				2014						
Liberia					2007		2009	2011			2013	2016	2019				
Madagascar	1992		1997		**2004**		2009	2011			2013	2016					
Malawi	1992		2000		**2004**		**2010**	2012			**2014**	2015	**2017**				
Maldives							2009				2017						
Mali	1987		**1996**		2001	2006					2013	**2015**	**2018**				
Morocco	1987	1992			2004												
Mozambique			1997		2003		2011				2015	2018					
Namibia			2000		2007						2013						
Nepal			1996		2001	2006					2016						
Nicaragua			**1998**		**2001**												
Niger	1992		1998		**2006**		**2012**										
Nigeria	1990				2003		2008	**2010**			**2013**	2015	2018				
Pakistan	**1991**				2007						2013	2018					
Peru	**1986**	1992	1996	2000	2006		2009	2010	2011	2012							
Philippines	1993		1998		2003		2008				2013	2017					
Rwanda	1992		2000		2005		2008	2010			2013	2015	2017				
Senegal	1986	1993	1997		2005	2006	2009	2011			2013	2014	2015	2016	2017	2018	2019
Sierra Leone							2008				2013	2016	2019				
South Africa			1998								2016						
Tajikistan							**2012**				2017						
Tanzania	1992		1996	1999	2005		**2008**	**2010**	**2012**		**2015**	2017					
Timor-Leste							2010				2016						
Togo	1988		1998								2014	2017					

Turkey	1993		1998	2003		2008		2013		
Uganda	1989	1995		2001	2006	**2009**	**2011**	**2015**	**2016**	2019
Vietnam			1997	**2002**						
Zambia	1992		1996	2002	2007			2014	2018	
Zimbabwe	1988	1994	1999	2006		2011		2015		

Notes: Normal font means that only DHS is included, bold font means that DHS as well as LSMS/HIS is included. N(DHS)=289, N(LSMS/HIS)=44.
Source: Authors.

B. Harmonization of regional boundaries across survey years

This section serves to illustrate in detail how we adjusted the region variable in order to obtain a region-level dataset with consistent regional boundaries over time.

Out of 60 countries in our dataset, 38 experienced changes with respect to boundaries of their administrative regions during the period of observation. In most cases, one or several regions where simply split into two or more smaller regions. While in some of these countries, only one or few regions were affected, in other countries the majority or all regions changed their boundaries. In all affected countries, we adjusted the regions while considering two criteria: first, consistency of regional boundaries over time, and second, no unnecessary omission of information. For the recoding, we used two broad approaches of regional adjustment, depending on how regional boundaries changed. The two following examples are used to illustrate this.

Approach 1: Pakistan was divided into four regions (Balochistan, Khyber Pakhtunkhwa, Punjab, Sindhin) in the 1998 and 2007 DHS. Later, the original Punjab region was split into two regions, 'Punjab' and 'Islamabad', leading to five regions (Balochistan, Khyber Pakhtunkhwa, Punjab, Islamabad, Sindhin) in the 2013 and 2017 DHS. Hence, we merged the regions 'Punjab' and 'Islamabad' in 2013 and 2017 resulting in four regions with consistent boundaries in all four survey years. This allows to control for region-fixed effects, while only 'loosing' two observations.[17] In short, for a given country, this approach leads to a consistent set of regions with the same boundaries across our entire study period.

Approach 2: Benin was divided into six regions (Atacora, Borgou, Atlantique, Mono, Oueme, Zou) in the 1996 and 2001 DHS. Later, in the 2006, 2012 and 2018 DHS, each of the six regions was split into two smaller regions, resulting in 12 smaller regions (Atacora / Donga, Borgou / Alibori, Atlantique / Littoral, Mono / Couffo, Oueme / Plateau, Zou / Collines). Here, instead of merging the smaller regions of the later years back to the original regions, we simply renamed the regions in 1996 and 2001 (Atacora_96/01, Borgou_96/01, Atlantique_96/01, Mono_96/01, Oueme_96/01, Zou_96/01). This still allows to control for region-fixed effects, since every region is at least twice in the data and regions are consistent between 1996 and 2001 and between 2006 and 2018. At the same time, we do not lose any variation, as opposed to losing 18 observations (3 x 6) had we decided to merge the 2006-2018 regions back to their original shape. So, for a given country, this approach leads to two different sets of regions, with each set of regions being included at least twice in consecutive survey years.

Table S2 shows for each country whether it experienced and changes in regional boundaries and, if so, which approach we used to harmonize the region boundaries over time.[18]

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[17] Sometimes regions were regrouped in a more complicated manner, such that some of the newly formed regions cross boundaries of old regions and thus can't be unambiguously allocated to one specific old region. Whenever these inaccuracies were small, we allocated the new region the old region with the biggest overlap. If this was not feasible, we tried to re-group both old and new regions in order to form consistent boundaries (of fewer but larger regions) over time. If neither was feasible, we excluded the affected DHS from our dataset.

[18] See https://spatialdata.dhsprogram.com/boundaries/#view=table&countryId=AF for a detailed illustration of all regional boundary changes for all DHS surveys.

Table S2: Overview of regional boundaries changes

No regional boundaries changes	Regional boundaries changes – Approach 1	Regional boundaries changes – Approach 2
Colombia	Angola	Benin
Comoros	Bangladesh	Bolivia
Congo, Dem. Rep.	Brazil	Burkina Faso
Egypt, Arab Rep.	Burundi	Nigeria
Ethiopia	Cambodia	Peru
Guatemala	Cameroon	Senegal
Guyana	Chad	
Kenya	Congo, Rep.	
Lesotho	Dominican Republic	
Malawi	Gabon	
Maldives	Ghana	
Mozambique	Guinea	
Namibia	Haiti	
Nepal	Honduras	
Nicaragua	India	
South Africa	Indonesia	
Tajikistan	Jordan	
Timor-Leste	Liberia	
Turkey	Madagascar	
Vietnam	Mali	
Zimbabwe	Morocco	
	Niger	
	Pakistan	
	Philippines	
	Rwanda	
	Sierra Leone	
	Tanzania	
	Togo	
	Uganda	
	Zambia	

Source: Authors.

C. Summary statistics for all sub-samples

Table S3 below presents summary statistics for all variables used in the regressions, separately for each sub-sample.

Table S3: Summary statistics by sample

Sample	1a	1b	2a	2b	3a	3b
	Mean	Mean	Mean	Mean	Mean	Mean
Fertility						
Regional total fertility rate (TFR)	4.295	5.223	4.056	4.918	4.777	5.061
Child mortality						
Child deaths (<5y.) per 1,000 live births	106.175	132.044	85.157	103.027	119.870	133.297
Urbanization						
Share of households located in urban area	0.400	0.352	0.423	0.376	0.370	0.317
Household wealth						
Weighted mean of household asset index	0.617	0.137	0.761	0.297	0.295	0.013
Female educational attainment						
Share of women with no education	0.252	0.342	0.191	0.273	0.320	0.371
Share of women with primary or higher education	0.748	0.658	0.809	0.727	0.680	0.629
Share of women with primary education	0.356	0.380	0.344	0.356	0.401	0.402
Share of women with secondary or higher education	0.391	0.278	0.466	0.371	0.280	0.227
Female occupational structure						
Share of women not working	0.413	0.358	0.405	0.369	0.349	0.288
Share of women working in agriculture	0.247	0.313	0.224	0.269	0.303	0.382
Share of women working in non-agricultural informal jobs	0.231	0.244	0.254	0.263	0.244	0.237
Share of women working in non-agricultural formal jobs	0.110	0.086	0.119	0.099	0.103	0.093
Industrialization						
Log of mean nighttime light intensity	3.138	2.636	3.472	3.468	2.148	1.896
Health insurance coverage						
Share of households with health insurance	-	-	0.197	0.082	-	-
Relative female wages						
Average male wage	-	-	-	-	432.947	429.942
Average female wage	-	-	-	-	304.864	309.248
Male to female wage ratio	-	-	-	-	1.788	1.845
Observations	1,952	1,011	767	427	259	197

Notes: Nighttime light intensity is measured on a continuous scale from 0 to 63 with higher values corresponding to higher nighttime light intensity. Wages are monthly wages in 2011 intl. $ PPP.
Source: Own calculations using data from DHS, LSMS (and similar surveys) and Li et al. (2020).

D. Wage regressions

Table S4 below presents the regression results when including relative female wages as indicator of structural change.

Table S4: Fertility regressions – relative female wages

Explanatory variables	All regions (1) Sample 3a	Sub-Saharan Africa (2) Sample 3b
Child mortality		
Child deaths (<5y.) per 1,000 live births	0.003** (0.0014)	0.003** (0.0015)
Urbanization		
Share of households located in urban area	-0.511 (0.3729)	-0.976*** (0.3579)
Household wealth		
Weighted mean of household asset index	-0.466** (0.1977)	-0.212 (0.1803)
Female educational attainment		
Share of women with primary education	-3.314*** (1.2577)	-3.334*** (1.2209)
Share of women with secondary or higher education	-1.265 (0.8070)	-1.229 (0.7806)
Female occupational structure		
Share of women working in non-agricultural formal jobs	-4.501*** (1.4261)	-4.331*** (1.5775)
Industrialization		
Log of mean nighttime light intensity	0.019 (0.0609)	-0.022 (0.0752)
Relative female wages		
Ln of mean male wage	0.121 (0.1671)	0.062 (0.1437)
Ln of mean female wage	-0.198*** (0.0422)	-0.178*** (0.0431)
Country-specific time-effects	yes	yes
Spatial lag of TFR	yes	yes
Region-fixed effects	no	no
R-Squared	0.844	0.821
Observations	259	197
Region groups	138	93

Notes: Each column refers to one regression. Robust standard errors clustered at the country level in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.
Source: Own calculations using data from DHS and Li et al. (2020).

E. Panel regressions

Table S5 presents the regression results when additionally controlling for region-fixed effects, for all samples.

Table S5: Fertility regressions – controlling for region-fixed effects

Explanatory variables	All regions				Sub-Saharan Africa			
	(1) Sample 1a	(2) Sample 1a	(3) Sample 2a	(4) Sample 3a	(5) Sample 1b	(6) Sample 1b	(7) Sample 2b	(8) Sample 3b
Child mortality								
Child deaths (<5y.) per 1,000 live births	0.005*** (0.0009)	0.005*** (0.0009)	0.007*** (0.0015)	0.005** (0.0023)	0.004*** (0.0010)	0.004*** (0.0010)	0.006*** (0.0015)	0.005* (0.0025)
Urbanization								
Share of households located in urban area	0.845** (0.4276)	0.983** (0.4364)	0.474 (0.4059)	-0.350 (1.0994)	0.677 (0.5697)	0.722 (0.5921)	0.134 (0.5857)	-0.503 (1.4470)
Household wealth								
Weighted mean of household asset index	-0.504*** (0.1413)	-0.331** (0.1529)	0.120 (0.1773)	0.165 (0.1495)	-0.461*** (0.1322)	-0.312** (0.1294)	0.263 (0.2788)	0.287*** (0.1073)
Female educational attainment								
Share of women with primary or higher education	-1.452*** (0.5375)				-1.315** (0.5559)			
Share of women with primary education		-0.874 (0.6775)	-0.729 (1.0340)	-0.306 (2.7072)		-0.876 (0.6205)	-0.219 (1.3946)	-0.279 (3.0187)
Share of women with secondary or higher education		-2.711*** (0.6728)	-3.316*** (1.2265)	-0.342 (2.2316)		-2.105** (0.8473)	-2.960* (1.7151)	-0.496 (2.3978)
Female occupational structure								
Share of women working in non-agricultural formal jobs		-0.780* (0.4456)	-0.510*** (0.1503)	-1.154 (1.6501)		-1.424 (0.8757)	0.123 (0.5642)	-1.752 (1.9252)

Industrialization								
Log of mean nighttime light intensity		-0.018	0.008	-0.004		0.000	0.012	-0.010
		(0.0208)	(0.0241)	(0.0470)		(0.0228)	(0.0216)	(0.0480)
Health insurance coverage								
Share of households with health insurance			-0.338				-1.869***	
			(0.2594)				(0.5708)	
Relative female wages								
Ln of mean male wage				0.067				0.078
				(0.1357)				(0.1461)
Ln of mean female wage				0.035				0.042
				(0.0456)				(0.0483)
Country-specific time-effects	yes	yes	yes	yes	yes	yes	yes	yes
Spatial lag of TFR	yes	yes	yes	yes	yes	yes	yes	yes
Region-fixed effects	yes	yes	yes	yes	yes	yes	yes	yes
R-Squared	0.687	0.692	0.760	0.755	0.634	0.640	0.802	0.760
Observations	1,952	1,952	767	259	1,011	1,011	427	197
Region groups	509	509	406	138	259	259	239	93

Notes: Each column refers to one regression. 13 regions in Sample 1a and 4 regions in Sample 1b have information on fertility and the explanatory variables for only one survey year and thus do not contribute to the panel regressions. 172 regions in Sample 2a and 97 regions in Sample 2b have information on fertility and the explanatory variables for only one survey year and thus do not contribute to the panel regressions. 52 regions in Sample 3a and 24 regions in Sample 3b have information on fertility and the structural variables for only one survey year and thus do not contribute to the panel regressions. Robust standard errors clustered at the country level in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.
Source: Own calculations using data from DHS and Li et al. (2020).