Women's Empowerment in sub-Saharan Africa

By

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Dedication

I would like to dedicate my dissertation work to Matthew Bond. It has been a long time coming and I am glad to finally return the favor.

Abstract

This project aims to improve our basic understanding of women's empowerment and develop a multi-component index that tracks empowerment over time and across space in sub-Saharan Africa. We first developed the Female Empowerment Index (FEMI) to track six domains of women's empowerment (Intimate Partner Violence, Access to Family Planning, Reproductive Healthcare, Employment, Education, and Decision-Making) at the sub-national level and applied it to Nigeria for five years to test its conceptual merit. We found clear geographic patterns in empowerment across space and time. Next, we used all available data across sub-Saharan Africa to calculate FEMI and its components for the years 1995, 2005, and 2015. We found that the median score increased by 0.09. However, there was considerable variation both within and between countries. We found a coastal-inland and north-south gradient within all domains other than employment. We also discovered worsening inequality within education and employment, and no progress in family planning access in northern SSA. Finally, we assessed potential economic, environmental, and social markers for their ability to accurately predict women's empowerment, based on FEMI scores in 2015. We tested all first-level administrative subdivisions in SSA as a result of travel time to the nearest city, distance to the nearest coastline, GDP per capita (PPP), population density, annual temperature, and rainfall. Models were made for the continent and four subregions (North/Western, Eastern, Central, and Southern). Only the North/Western and Eastern regions were different from the null model. Population density was consistently one of the most important predictors and showed a strong positive effect on women's empowerment even at relatively low densities, with distance to the coast being the second most important factor. Understanding the past and current status of women's

empowerment and some of its predictors may help push forward improved intervention targeted and an understanding of the factors underlying empowerment.

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Chapter 1. The Female Empowerment Index (FEMI): spatial and temporal variation in women's empowerment in Nigeria

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Abstract

Improving female empowerment is an important human rights and development goal that needs to be monitored. A number of indices have been developed to track female empowerment at the national level, but these are incomplete and may obscure important sub-national variation. We developed the Female Empowerment Index (FEMI) to track multiple domains of women's empowerment at the sub-national level. The index is based on six categories of empowerment: violence against women, employment, education, reproductive healthcare, decision making, and access to contraceptives. The FEMI has a range of zero to one (low to high empowerment), and it is calculated as the mean proportion of positive outcomes in the six categories. To provide a proof of concept, we computed the FEMI for Nigeria and its 36 states from five Demographic and Health Surveys between the years of 1990 and 2013, using questions asked to 98,542 women between 15 and 49 years old. At the national level, the FEMI increased from 0.34 to 0.48. However, there was substantial sub-national variation, with state-level values ranging from 0.16-0.60 in 1990 to 0.19-0.73 in 2013. The FEMI can be readily computed

for other countries, and its ability to track spatial and temporal variation in woman's empowerment across a broad set of categories may make it more useful than existing approaches.

Introduction

Increasing the empowerment of women is a major human rights and development goal (Gates 2014; UN General Assembly 2014), but progress in women's empowerment lags behind development goals in other domains, particularly in sub-Saharan Africa (United Nations 2015). In addition to its intrinsic human rights value, empowering women can result in benefits for societies at large. For example, increases in women's empowerment can lower infant and child mortality (Gakidou et al. 2010; Knippenberg et al. 2005) and improve health and nutrition. Improvements in women's education is also linked to strong gains in income (Psacharopoulos 1994).

Meaningful indicators are necessary to identify and understand patterns and trends in woman's empowerment to guide and evaluate policy and other intervention efforts. Unfortunately, detailed spatial and temporal data on indicators of female empowerment are generally lacking (UN Women 2016). Furthermore, empowerment has multiple dimensions, and there is no one obvious way to measure it. Different empowerment approaches have been developed by the UNDP, including the Gender Development Index (GDI) and Gender Empowerment Measure (GEM) (UNDP, 1995), and the follow-up Gender Inequality Index (GII) (Gaye et al. 2010). The Gender Development Index (GDI) uses data on life expectancy, literacy and educational enrollment rates, and income. The Gender Empowerment Measure (GEM) uses data on higher-status employment positions, political participation, and income. Both the GDI and GEM

primarily focus on “gender gaps”, that is, differences between women and men. The GII was designed to address some of the criticisms of the GDI and GEM. It captures aspects of reproductive healthcare via the maternal mortality rate and adolescent birth rate, as well as education rates, parliamentary representation, and labor force participation rates. The GII takes into account both absolute values (for women only) as well as relative values (gender-gaps). However, aspects of decision making and personal security are not included. The Global Gender Gap Index (GGGI) (World Economic Forum 2019) is an alternative index created by the World Economic Forum to highlight national-level achievement gaps between women and men in four categories: Economic Participation and Opportunity, Educational Attainment, Health and Survival and Political Empowerment. It is exclusively uses gender gaps.

A primary limitation of all of four indices is that they have been designed for and computed at the national level, obscuring within-country variation that may be important for policymaking and intervention efforts. Their utility has also been limited by using variables that are widely available, but not necessarily most indicative of women’s empowerment. This is particularly problematic for assessing the status of women at lower economic strata. For example, the variables used for employment categories largely pertain to the most educated and economically advantaged women because the available data ignored the informal employment sector (Cueva Beteta 2006). Another criticism of these measures is their lack of information on important empowerment dimensions decision making and personal security (Hirway and Mahadevia 1996; Klasen 2006).

The increasing availability of nationally representative survey data has created opportunities to more fully capture women's empowerment by including additional dimensions of empowerment. Ewerling et al. (2017) used 15 questions from the Demographic and Health Surveys across Africa to compare countries in three domains of female empowerment: attitude to violence, decision making, and social independence.

In an effort to improve upon these measures and to better understand the changes in the empowerment of women over space and time, we developed the Female Empowerment Index (FEMI). The FEMI use nationally representative survey data to compute sub-national variation in important aspects of empowerment, some of which were not included in previous indices, including all types of employment, personal agency and decision making, physical and sexual violence, and access to reproductive health services. Apart from adding these domains of empowerment, the FEMI also addresses shortcomings in previous indices by including both the formal and informal employment sector and considers both gender gaps and absolute levels of empowerment. The FEMI can be computed with the Demographic and Health Surveys (DHS) data, which are available for most countries in Sub Saharan Africa, and for many countries in Asia and the Americas. The FEMI is computed by averaging scores in six empowerment categories: violence against women, employment, education, reproductive healthcare, decision making, and access to contraceptives. To illustrate its use and provide a proof of concept, we implemented the FEMI for the 36 states of Nigeria, using 19 questions from DHS for five survey years.

Materials and methods

Data sources

We used all available data from the Demographic Health Surveys (DHS) program in Nigeria for the years 1990, 1999, 2003, 2008, and 2013 (ICF International, 1992-2014). These years represent all standard DHS surveys conducted in country to date. In total, 98,542 women aged 15-49 years were interviewed. The first three surveys had smaller sample sizes; the average number of women interviewed was around 8,200 for the first three surveys and 36,000 for the last two. Table 1.1 summarizes some of the general characteristics of the population surveyed across years.

Table 1.1: Mean characteristics of women for the Demographic and Health Surveys in Nigeria, by survey year. Characteristics that were not included in a given survey are marked with "-"

Characteristic		Survey Year				
		1990	1999	2003	2008	2013
Age		28.17	27.95	28.02	28.65	28.86
Wealth Quintile		-	-	3.07	2.92	3.12
Married		76.3%	70.2%	67.7%	71.8%	70.0%
Number of Children		3.20	2.84	3.02	3.14	3.07
Religion	Christian	47.3%	53.9%	51.0%	51.7%	51.2%
	Islam	48.7%	44.3%	47.3%	46.5%	47.9%
	Traditional/Other/None	4.0%	1.8%	1.7%	1.8%	0.9%

The actual number of responses varied by question (Table 1.2), as some questions were asked only to specific categories of women, as was in the case of access to contraception, reproductive healthcare, and employment.

Table 1.2: Effective sample size by FEMI category and number of survey sites ("clusters") for the Demographic and Health Surveys in Nigeria, by survey year. Categories that were not included in a given survey are marked with "-".

Category	Survey Year				
	1990	1999	2003	2008	2013
Violence against Women	7079	6081	7473	32825	38551
Employment	-	8166	7613	33326	38913
Education	8767	8180	7620	33383	38945
Reproductive Healthcare	4873	3067	3767	17995	20192
Decision Making	-	-	7374	23880	27210
Access to Contraception	1987	2135	2686	12220	14687
Number of Sites	299	399	365	888	904

Categories were created based on either the responses to single questions (employment and contraception) or the mean response to several related questions (education, decision making, violence against women, and reproductive healthcare; see Table 1.3). All responses were recoded such that their values ranged between zero and one, where zero represented low levels of empowerment and one represented high empowerment. Thus, the value of a given FEMI category can be interpreted as "the proportion of positive outcomes in this category". The FEMI index was calculated as the mean of all categories and has a theoretical range of zero to one, with one being the highest level of empowerment.

Responses from individual women were aggregated to state level for the 36 Nigerian states using the geographic coordinates of survey sites (referred to as “clusters” by DHS). In 1990, Nigeria had only 30 states. In order to allow direct comparisons to later surveys, we aggregated the individual 1990 data to the modern 36 states based on where they would have lived in the newer 36 state scheme. In addition, the 1999 survey did not release survey site coordinates; the only geographic reference provided for a respondent was being located in one of five large regions, each consisting of multiple states. In order to allow direct comparison between this survey and other surveys, we downscaled the responses for this survey by taking the year-weighted mean of the 1990 and 2003 surveys for each state and applying a linear adjustment factor to ensure that the overall regional mean matched that of the original 1999 survey regions.

Some categories were not included in all surveys, generally in the 1990 and 1999 survey years (Table 3). Responses to the questions in these categories were estimated at the state level using the RandomForest algorithm (Breiman 2001). Predictor variables used were responses to questions that were available for all surveys: year, access to contraceptives, reproductive healthcare, age at first marriage, age at first child, years of education, milieu (urban/rural), respondent’s age, number of respondent’s births in the last 5 years, and geographic coordinates of the respondent’s state. For the men’s employment and education questions, year, milieu (urban/rural), respondent’s age, and geographic coordinates of the respondent’s location were used as predictor variables.

In some cases one can either examine absolute values for women’s empowerment in a particular category or express them relative to men’s achievement in the same category. For the education and employment categories, we chose to use relative

values. These were computed for each state i by multiplying them by the inequality coefficient (women's value / men's value, capped at one):

$$Inequality\ adjusted\ value_i = women's\ value_i \times \left(\frac{women's\ value_i}{men's\ value_i}\right)$$

This method was chosen because it results in the highest adjustment for states that have both high absolute levels and high relative differences. For example, if 60% of women and 80% of men have primary education, the unadjusted value would be 0.60 and the inequality-adjusted value would be 0.60 × (0.60 ÷ 0.80) = 0.45, for an absolute decrease of 0.15. However, if 20% of the women and 40% of the men have primary education (the same 20% difference), the unadjusted value would be 0.20 and the inequality-adjusted value would be decrease to 0.20 × (0.20 ÷ 0.40) = 0.10, for an absolute decrease of 0.10. The heavier penalization of regions that have a relatively high welfare but high levels of inequality is desirable, as it helps to avoid giving low scores to regions for merely being poor. Adjustment was unnecessary for the decision making category because questions in the category already account for differences in women's and men's decision making, and adjustment was irrelevant to the reproductive healthcare, violence against women, and contraception categories.

To ensure that our results were not skewed by using DHS data sub-nationally (most DHS statistics are aggregated to the national level in reporting), we examined several potential areas of concern. First, DHS surveys oversample poor and rural households. This is normally corrected for when computing national level aggregate values by using DHS-provided weights. Because of a lack of data on state-level wealth distributions, we have used unweighted data for each state, which may artificially lower values for

wealthier states. To assess the potential impact of this issue, we created national unweighted values by taking the unweighted mean of state level categories for each year and compared them to the DHS-weighted national category results.

Additionally, aggregating DHS data by sub-national regions rather than for the entire country could result in noisy data due to low sample sizes. This would be of particular concern for the 1990-2003 surveys, as they have a lower sample size compared to the later surveys, with an average of 248 individuals sampled per state in the 1990, 1999, and 2003 surveys, whereas 1,005 individuals were sampled per state in the latter two surveys. We evaluated the degree to which the data was spatially noisy by computing Moran's *I*, a measure of spatial autocorrelation, for each category of the FEMI. Spatial autocorrelation expresses the extent to which geographically near regions are more similar to each other than geographically distant regions. For most development indicators we would expect high levels of positive spatial autocorrelation, and low spatial autocorrelation values would then suggest poor data quality, perhaps due to a low sample size. Moran's *I* runs from negative one (complete negative spatial autocorrelation) to one (complete positive spatial autocorrelation). We tested these results for statistical significance by comparing observed statistics to Monte-Carlo-simulated distributions (n=999).

A final issue we considered is the effect of a time lag for certain indicators like education and age at first marriage. As the index is computed for women between 18 and 45, a cohort of women is in the sample for 27 years (that is, longer than the 23 year span of the five surveys we used). This may dampen the apparent changes for some questions and categories. For example, a woman first married at the age of 17 will still have that

status when she is 45, even if the practice of adolescent marriage has become much less common in more recent years. Educational achievement is similarly affected. To detect potential dampening of changes, we analyzed the values for applicable categories by adjusting for the current age of respondent (as of 2013).

Computation of the empowerment categories

Violence against Women

The DHS surveys include questions on women's direct experience with physical and sexual violence. The survey data suggested that about 5% of Nigerian women experienced physical and/or sexual violence across survey periods. This is significantly lower than reported rates of 21%-36% for physical violence and 33%-64% for sexual violence (Antai and Antai 2008; Fawole, Aderonmu, and Fawole 2005; Ilika, Okonkwo, and Adogu 2002; Okemgbo, Omideyi, and Odimegwu 2002; Okenwa, Lawoko, and Jansson 2009; Olagbuji et al. 2010). This discrepancy is probably due to a reluctance to report on this sensitive issue. Because of this concern about the data quality, we instead used five questions related to attitudes regarding the justification of violence as a proxy for physical violence (see Antai & Antai, 2008; Oyediran & Isiugo-Abanihe, 2005). For sexual violence, adolescent marriage was used as a proxy, both because it indicates a lack of control over a woman's sexual choices (Nour 2006) and because early marriage may be considered an act of sexual violence in its own right (Gottschalk 2007). The overall violence against women score was calculated as the mean of the averaged justification of physical violence questions and adolescent marriage rates to represent an equal weight between physical and sexual violence.

Table 1.3: Categories, questions, and years data for which a given question was not asked (values were imputed). Answers to all questions were converted to Yes/No.

Category	Question	Years of Estimation
Violence Against Women	Childhood marriage: Did respondent have a child before the age of 18?	
	Is beating justified if respondent goes out without telling her partner?	1990, 1999
	Is beating justified if respondent neglects the children?	1990, 1999
	Is beating justified if respondent argues with her partner?	1990, 1999
	Is beating justified if respondent refuses to have sex?	1990, 1999
	Is beating justified if respondent burns the food?	1990, 1999
Employment	Have you had paid employment (cash or in-kind) within the past 12 months?	1990
Education	Primary educational attendance: Did respondent attend at least 6 years of school?	1990 (men only)
	Literacy: Can respondent read a short paragraph shown to them?	1990, 1999
Reproductive Healthcare	Did respondent have a prenatal visit for her most recent child?	
	Childhood birth: Did respondent have a child before the age of 18?	
	Was respondent's most recent child delivered in a professional setting?	
Decision Making	Does respondent have a say in her health?	1990, 1999
	Does respondent have a say in large purchases?	1990, 1999
	Does respondent have a say in household purchases?	1990, 1999, 2013
	Does respondent have a say in visits to family?	1990, 1999
	Does respondent have a say in food to be cooked?	1990, 1999, 2008, 2013
	Does respondent have a say in deciding what to do with money?	1990, 1999, 2003
Access to Contraceptives	Are you using modern contraception if you are married and do not currently desire more children?	

Employment

All women who received payment for labor in the 12 months prior to the interview were counted as employed. This included women who were paid in cash, in-kind, or a combination of the two; unpaid work was excluded. Including in-kind and mixed payments helps bridge the gap between the formal and informal employment sectors, the latter of which is an important source of employment for many women in rural areas and in lower income areas. This category includes seasonal and occasional work, and should not be interpreted as the number of women who have steady paid jobs. The employment data was available for married women only, and for this reason it had a smaller sample size than other categories.

Education

The educational category was computed as the average of the responses to two questions. Primary educational rates were calculated as the proportion of women who have attended at least six years of schooling. Literacy rates were calculated as the proportion of women who could read a simple paragraph without difficulty. Those who couldn't read, or read only with difficulty, were categorized as unable to read.

Reproductive Healthcare

The reproductive healthcare category was computed as the average of the responses to three reproductive health questions (Table 1.3). No imputation was needed for this category.

Decision Making

The decision making category was computed as the average of the answers to six questions. The answers “self” and “self and partner” in response to questions regarding who had the primary say in different aspects of decision making were combined into “yes” (Table 1.3).

Contraception

For the contraception category, we wanted to capture whether women in need of contraception were able to obtain and use it. Our methods are based on the STATA code released by DHS (Bradley and Croft 2017) that follows the methods of Bradley et al. (2012). It should be noted that their publicly available code does not match their stated methodology (i.e. they claim to measure only married women, but their code does not actually exclude unmarried women from analysis, except in some infecundity checks). We have fixed the code to examine only married women as recommended by DHS, and we have fixed several errors that misclassify women who have missing data, as well as a typo that misclassified infecund women incorrectly.

We then used a modified recoding of the results to reflect our particular needs. In essence, our sample was first restricted to married fecund women who did not want more children at the time of the survey. These women were then classified based on whether or not they were currently using modern contraceptive methods. Infecund women, women who wanted additional children at the time of the survey, and those using traditional methods (e.g., withdrawal) or folklore-based methods (e.g., charms) were removed from analysis. This categorization is an improvement over the original

DHS methods for our purposes because our method only includes women who do not currently want children in the analysis. DHS also counts women who currently want children as having access to contraception, when that may or may not be true. However, this resulted in a lower sample size than for other categories (see Table 1.2).

Table 1.4. Model fit for the Random Forest estimation of missing values. R^2 values are internally calculated by Random Forest using the ("out of bag") data that were not included in the bootstrapped sample for a particular decision tree. R^2 values for questions that were only estimated for men or were estimated for both men and women are labeled with M and W, respectively. Unmarked values apply to women. Questions not in Table did not need imputation.

Category	Question	R^2
Violence Against Women	Is beating justified if respondent goes out without telling her partner?	0.56
	Is beating justified if respondent neglects the children?	0.44
	Is beating justified if respondent argues with her partner?	0.40
	Is beating justified if respondent refuses to have sex?	0.57
	Is beating justified if respondent burns the food?	0.43
Employment	Has respondent had paid employment (cash or in-kind) within the past 12 months?	W: 0.28 M: 0.31
Education	Can respondent read a short paragraph shown to them?	W: 0.97 M: 0.75
	Did respondent attend at least 6 years of school?	M: 0.66
Decision Making	Does respondent have a say in her health?	0.72
	Does respondent have a say in large purchases?	0.74
	Does respondent have a say in household purchases?	0.70
	Does respondent have a say in visits to family?	0.62
	Does respondent have a say in food to be cooked?	0.51
	Does respondent have a say in deciding what to do with money?	0.54

Regions

Several empowerment categories showed a strong north/south divide. Nigeria is commonly grouped into six regional geopolitical zones. For the purposes of reporting some of the differences between north and south, we combined the North West and North East geopolitical zones, representing roughly the northern third of the country, into the “North” region (the states of Adamawa, Bauchi, Borno, Gombe, Jigawa, Kaduna, Katsina, Kano, Kebbi, Sokoto, Taraba, Yobe and Zamfara). The North Central zone (representing the middle third of the country) was combined with the three southern zones to create the “South” region (all other states).

Results

Data quality

Our ability to impute missing data had variable quality, with R^2 values between .28 and .97 (Table 1.4). Estimation quality was significantly bolstered by strong temporal trends in the data; time (survey year) was the most important predictor for all estimated variables.

In testing for potential inaccuracies due to our use of unweighted state-level values, we calculated both the unweighted national means using the raw data and the weighted national means using the DHS-provided weights, and then calculated the absolute value of the differences. We found that the overall mean difference in FEMI categories was 0.03. Violence was the least affected with a difference of 0.01 and access to contraception was the most affected with a difference of 0.06. These results suggest

that the effect of using unweighted averages is generally small within individual categories and for the FEMI, although there does appear to be some mild suppression of values in wealthier states for access to contraception.

Excessive noise due to reduced sample size did not appear to be a major problem. We found that there were strong signs of spatial autocorrelation in each FEMI category, as well as consistent patterns over time (Figures 1.1 and 1.2). Moran's *I* values were above 0.60 for all categories except for contraception (0.51) and employment (0.39), indicating moderate to strong positive spatial autocorrelation. All Moran's *I* values were significantly different from zero at the $\alpha=0.05$ level except for the employment category for 2008 (p-value=0.13).

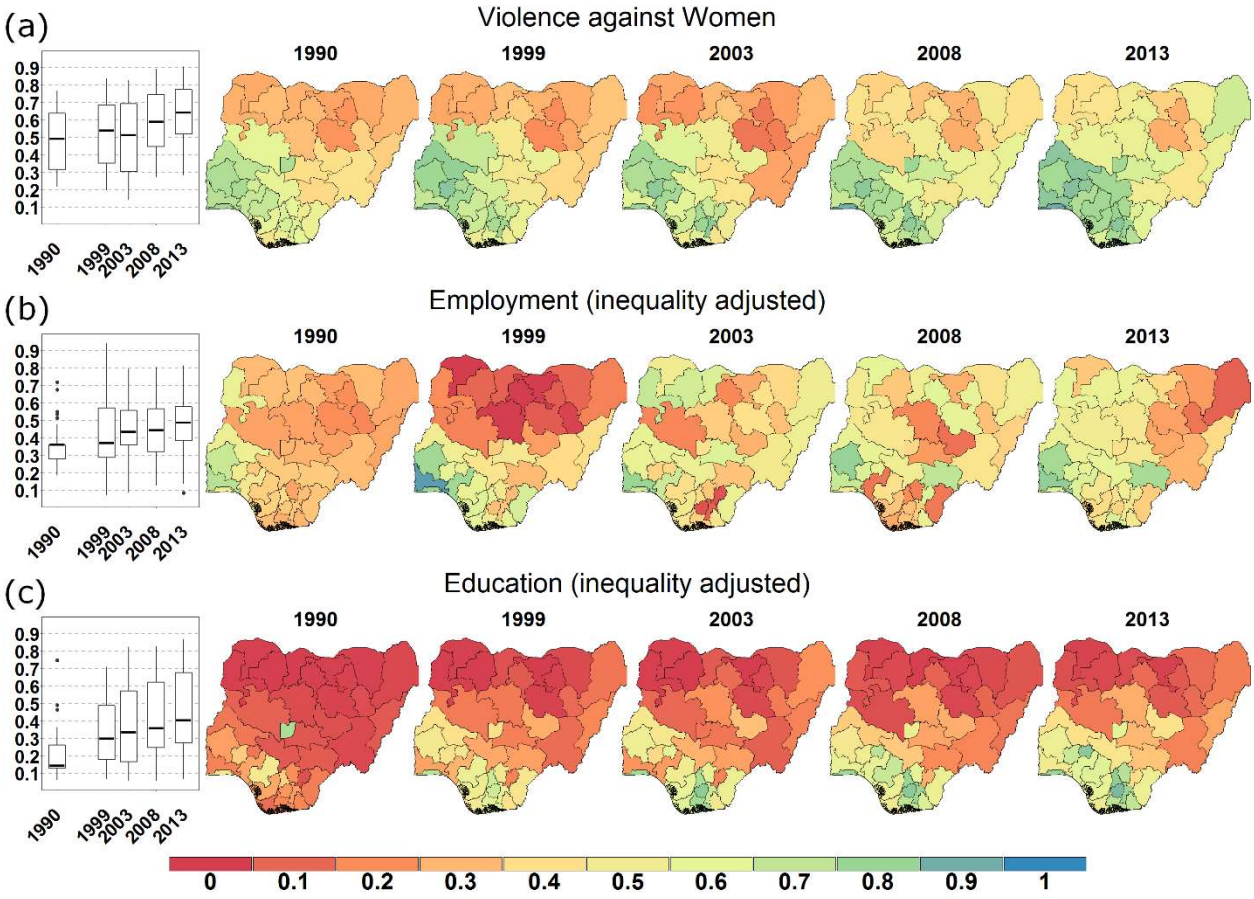

Figure 1.1: Three FEMI categories in Nigeria at the national (boxplot) and state level (maps) between 1990 and 2013. Boxplots were made using state level data, but with the median (thick horizontal bar) adjusted for population size to better reflect the true national median. **(A)** Violence against women. Higher values indicate lower levels of violence. **(B)** Inequality-adjusted employment of women. **(C)** Inequality-adjusted educational achievements by women. All three categories are calculated from the mean values in their respective categories, and then employment and education were adjusted for inequality between women and men.

Violence against Women

The experience and acceptability of violence against women decreased steadily over time, with the score for this category improving by 0.07 per decade (Figure 1.1). Violence against women is much more common in northern Nigeria, with adolescent marriage rates approaching 65% in the North in 2013 versus 23% in the South. The

reported acceptability of violence declined at a comparable rate. In northern states, the category went from 0.48 to 0.71 (0.10 per decade) and in southern states went from 0.67 to 0.82 (0.07 per decade) between 1999 and 2013.

Employment

Inequality-adjusted participation in gainful employment for women increased from 0.37 in 1990 to 0.49 in 2013 (Figure 1.1). The national equality gap was slightly lower in the 1990s (average of 0.67) and higher thereafter (average of 0.82) (Table 1.5). Employment for women lacks the typical north/south differences found among other FEMI categories which may indicate either relative geographical equality or noise in the data. Results for 1990 in particular should be interpreted with caution as these values were imputed with a RandomForest model for which the R^2 was only 0.28 for women and 0.31 for men.

Education

Average educational achievement for women has steadily increased, albeit with large sub-national variation. At the national level the education category went from 0.15 in 1990 to 0.41 in 2013 (Figure 1.1). Gender inequality in education is substantial, but it has diminished: in 1990 only four women had a primary education for each ten men; this increased to almost seven women for each ten men in 2013. Both relative and absolute educational gains have been achieved primarily in the South, with a number of northern states barely improving during the study period. In fact, the educational gap between North and South during the survey period actually widened; the non-adjusted mean difference between the two went from 0.30 to 0.46 between 1990 and 2013 and

the interquartile range nearly doubled. It is particularly striking that in the most educationally impoverished northern states less than 10% of the women have basic education and literacy while in some southern states nearly 90% of the women have achieved basic education and literacy.

Table 1.5: Mean weighted national original FEMI category values, gender inequality coefficients (ratio of women's / men's rates), and adjusted FEMI category values for the education and employment categories for the years 1990-2013 in Nigeria. The inequality-adjusted value is calculated by multiplying the original value by the relative inequality gap, which is the ratio of women's achievement to men's achievement.

		Year				
		1990	1999	2003	2008	2013
Education	Original value	0.27	0.40	0.43	0.44	0.49
	Inequality coefficient	0.40	0.64	0.63	0.65	0.69
	Adjusted value	0.15	0.30	0.34	0.36	0.41
Employment	Original Value	0.50	0.47	0.51	0.52	0.59
	Inequality coefficient	0.71	0.63	0.82	0.84	0.81
	Adjusted value	0.36	0.37	0.44	0.45	0.49

We found evidence for an age cohort effect for educational attainment, indicating that the expected outcomes for young adults is better than captured by the individual FEMI category values. In 1990, 32% of women ages 15-30 had at least six years of education compared to 7% of women from ages 35-49 and by 2013 those numbers had climbed to 54% and 34%, respectively.

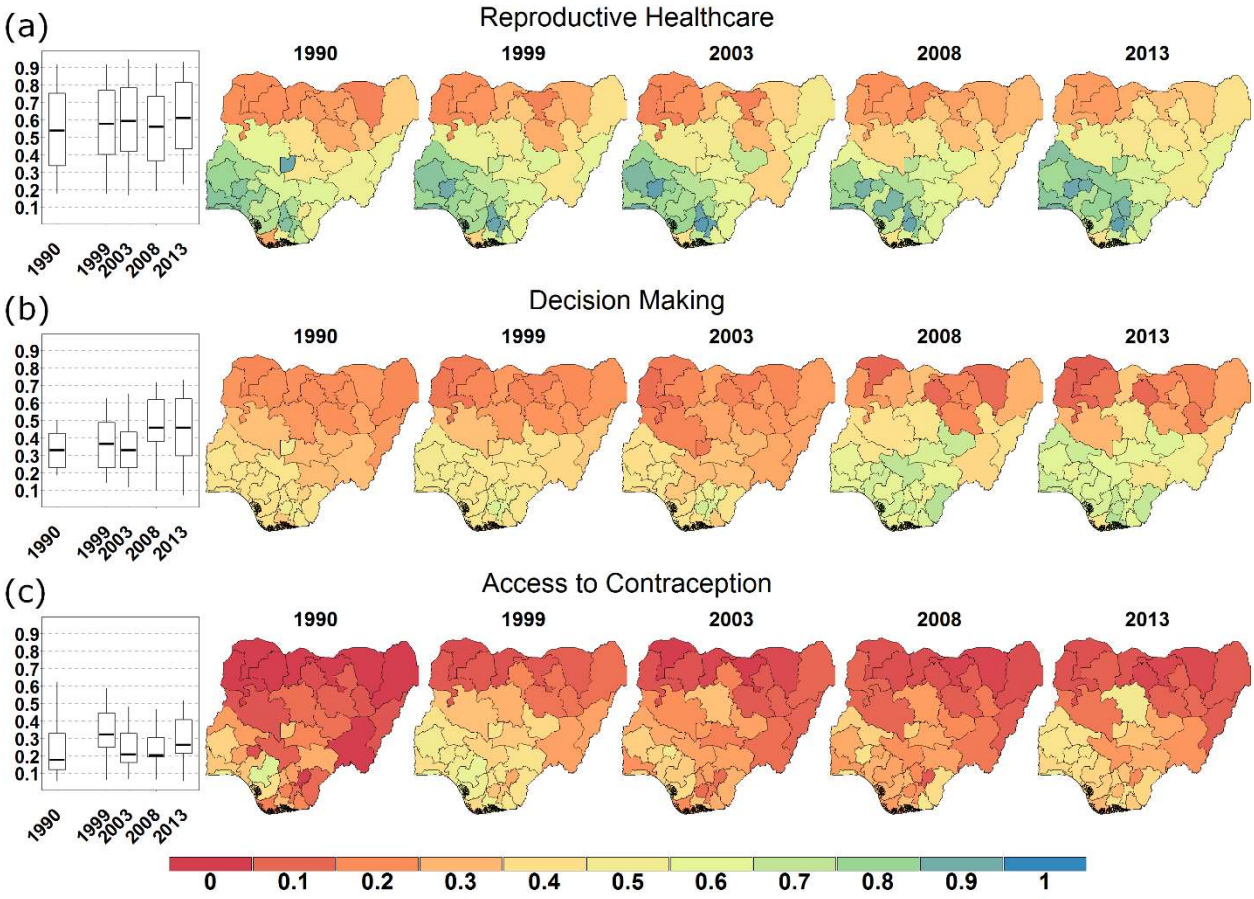

Figure 1.2: Three FEMI categories in Nigeria at the national (boxplot) and state level (maps) between 1990 and 2013. Boxplots were made using state level data, but with the median (thick horizontal bar) adjusted for population size to better reflect the true national median. **(A)** Reproductive healthcare of women. **(B)** Participation in decision making regarding their personal lives by women. Higher levels indicate greater control over decision making. **(C)** Access to contraception.

Reproductive Healthcare

The reproductive healthcare category showed only small gains, rising from 0.54 in 1990 to 0.61 in 2013. The use of prenatal visits and professional care settings for childbirth is very common in the South (84% and 63% in 2013, respectively), but rarer in the North, with only 50% of women having a prenatal visit and 17% using a professional setting for childbirth in 2013. The proportion of women having children as adolescents increased in the North during the survey period, rising from 0.65 to 0.74, while in the South values

were relatively steady, varying between 0.42 and 0.46.

Decision Making

Female participation in decision making improved from 0.33 in 1990 to 0.46 in 2013. The data suggests that gains were mainly achieved between 2003 and 2008, jumping 0.13 in this time period. However, the values for this category for the years 1990 and 1999 were imputed, as well as the values for some individual questions in the 2003, 2008, and 2013 surveys, so there is some uncertainty regarding the trend for this variable. The gap between the North and South appears to have widened, with women's ability to make decisions holding steady in the North with an average of 0.23 during the survey period but improving from 0.41 to 0.60 between 1990 and 2013 in the South.

Access to Contraception

Between 1990 and 1999 the access to contraception increased from 0.17 to 0.26. However, access to contraceptives dipped 0.12 between the 1999 and 2003 surveys and has not fully recovered since. Post-1999 gains are concentrated primarily in the South, with 44% of women having access to contraceptives in 2013 compared to only 12% of women in the North.

Female Empowerment Index

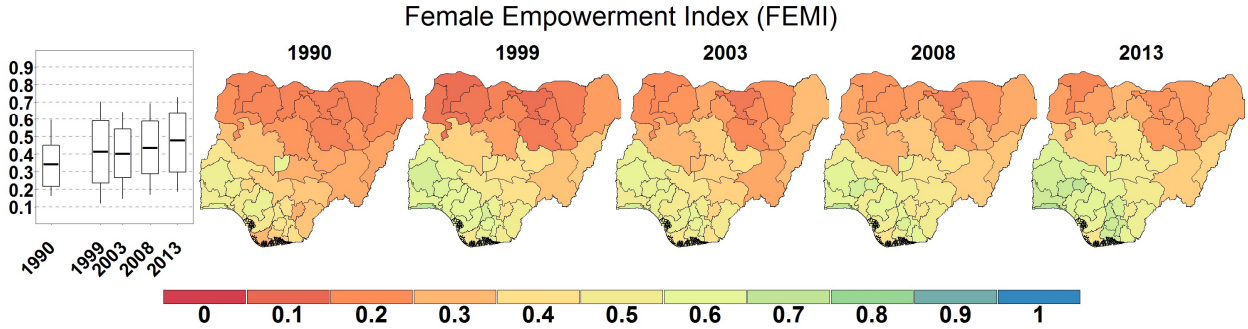

Figure 1.3: The Female Empowerment Index for Nigeria at the national (boxplot) and state level (maps) between 1990 and 2013, computed as the equally-weighted average of the six FEMI categories (violence against women, employment, education, reproductive healthcare, decision making, and access to contraceptives). Boxplots were made using state level data, but with the median (thick horizontal bar) adjusted for population size to better reflect the true national median.

The Female Empowerment Index has increased significantly during the 23-year survey period. With the exception of the access to contraception category, values in 2013 are the highest they have ever been, with lower levels of violence, and higher levels of health, education, decision making, and gainful employment for women across Nigeria. The national level FEMI was 0.34 in 1990 and 0.48 in 2013. The state and regional variation in the FEMI was substantial for all survey years. For individual states it ranged from 0.16 to 0.62 in 1990 and from 0.19 to 0.75 in 2013. The FEMI gap between the North and South actually widened during the survey period, going from 0.25 in 1990 to 0.32 in 2013.

While the FEMI is attractive as it provides a single number, it is interesting to consider trends in individual categories and how they contribute to changes in the FEMI. Improvements in the FEMI between 1990 and 1999 were largely driven by improved access to contraceptives in the South and improved employment in the North. From

1999-2003, there was reduced access to contraceptives in much of the country, but the FEMI did not decrease as there were gains in the other categories, particularly employment. From 2003-2008, the primary drivers of change in the FEMI were more varied, including a mix of improvements in violence, decision making, contraception, and employment. Changes between the 2008-2013 surveys came from a relatively equal mix of improvements in all six FEMI categories.

Discussion

There is much interest in improving the empowerment of women. This is clearly illustrated by its inclusion in the UN Sustainable Development Goals. A better monitoring of women's empowerment can be an important step toward improving it; but this has proven to be a very difficult task, both conceptually and methodologically. It is not entirely clear what exactly empowerment means and how to measure it. In addition, limitations in data availability have led to the use of widely data leading to sub-optimal measurements of empowerment.

We have addressed some of these conceptual and methodological problems by using DHS data to develop a new index to measure women's empowerment and using survey data to implement it in Nigeria at the sub-national level for five years. The FEMI captures most of the primary aspects the empowerment measures developed by the UNDP (political empowerment is the only exception) and adds women-specific contraception measures, violence against women, decision making, and additional women's reproductive healthcare variables. Thus, the FEMI captures more aspects of female empowerment and for a wider socioeconomic strata than has been achieved with previous indices. Creating a sub-national index is a logical next step in the

measurement of women's empowerment, and we have shown the importance of doing so given the wide variation in empowerment among Nigerian states.

DHS data is available for 90 predominantly lower income and lower-middle income countries, and the index could be applied to many of these countries as well. Sexual and physical violence data reported by DHS were far off other figures reported in the literature. Because the data were relatively uniform across the country, simple solutions like linear adjustments based on other reported figures were not possible. Improving the physical and sexual violence response rates in the DHS empowerment module as well as making the raw response data available for all surveys would be a great step forward in determining the past and current status of empowerment.

DHS sample sizes are quite large, and data quality was generally sufficient to support statements about the spatial and temporal variation in woman's empowerment. The 1990 and 1999 surveys had low sample sizes compared to the latter three surveys, but there were clear and persistent spatial and temporal patterns at the state level, illustrated by the high spatial autocorrelation. The relatively low spatial autocorrelation for employment may be a reflection of noise due to the relatively small sample size or because there truly is weaker spatial autocorrelation for this category. Additional research is needed to determine which is the case in order to inform future index revisions.

Certain DHS questions, including age at first marriage, age at first child, educational level, and literacy rates are highly sensitive to age. Responses to these questions were consistently more positive for younger women compared to older women. It is possible that accuracy could be affected if age cohorts are not similar in size across time. While

this does not appear to be the case for Nigeria (Table 1.1), it could be an issue while computing FEMI in other countries. In our case, the average age of the respondents was 28 to 29 years old. If the average age were different in another survey, age-corrected values could be computed. If large age variation is detected, one could, instead of using the average across age groups, use all data to estimate the values for a particular age group (e.g. 28-29 years old).

Imputing data for missing questions and categories was essential to provide a full picture of women's empowerment across all survey years, especially the 1990 and 1999 surveys, but doing so introduces uncertainty and should be therefore be undertaken carefully. In this case, quality of the imputed data were variable. While RandomForest models for education were almost perfect ($R^2 = 0.98$), this was not the case for all questions, especially for questions where there was a reduced sample size, such as the employment and access to contraception categories, which are only available for married women. Because of the strong temporal trends in the data, survey year was the most important predictor variable for almost all imputations.

Newer DHS surveys also have several interesting questions regarding women's experience of emotional violence. Unfortunately, in the case of Nigeria, these questions were only asked for the 2008 and 2013 surveys and our Random Forest imputation model was very poor for these questions ($R^2 = 0.12$), so we did not include them in FEMI. Additional research on finding better predictor variables for these categories might improve the results and allow inclusion of emotional violence, which would also improve the breadth of FEMI.

Developing an index like the FEMI is a balancing act between creating an ideal measure that captures as many aspects of empowerment as possible while making practical decisions of what to include and exclude based on data availability and quality. We have shown that the DHS surveys are an important source of multidimensional data suitable for analyzing women's empowerment. DHS surveys are very similar between countries and over time, although some empowerment-related questions are more commonly available in more recent surveys due to the creation and inclusion of the empowerment module in 1999. However, it should be noted that the module does not appear to be widely utilized until the mid-2000s, as was the case for Nigeria.

It is not possible to directly externally validate the quality of the FEMI for Nigeria as there is no alternative estimate for sub-national data. Ewerling et al. (2017) compare their national level DHS results with the GDI and found reasonable correspondence despite the fact that the GDI uses different data and has well-known flaws, suggesting that computations of these indices may be robust against differences in methods and data used. Establishing whether this is indeed the case is an important area of future research, among other things by computing the FEMI for other countries and comparing the national level results with the GDI and GII.

We believe that FEMI is likely to be superior to the GDI and GII on logical grounds. The GDI uses only the formal sector of earned income, which limits its ability to track the progress of women in lower socioeconomic strata. GDI is also not a freestanding measure – it effectively subtracts from the Human Development Index (HDI) based on gender inequality. Thus it is neither independent of overall development, nor an index that focuses on overall women's empowerment beyond gender gaps. The GII and GDI

share the same flaw of failing to adequately account for women of lower socioeconomic strata. They only include the formal employment sector rather than both the formal and informal sectors, which we have overcome by including unpaid and in-kind work. One third of the GII consists of formal labor force participation, and another sixth consists of parliamentary representation. While important, parliamentary representation is unlikely to be applicable to most women, especially the most poor and disadvantaged.

To calculate the FEMI, we computed the unweighted mean of the six empowerment categories. It is possible to compute a weighted mean or to use different methods to combine the categories. Our goal was to develop a simple index that provides an absolute measure that can directly be compared between studies. However, the FEMI categories are inherently important, independent of the index, and we have made these available by state to allow for the examination of individual categories or the use of alternate weighting schemes (see Appendix 1).

Conclusions

FEMI is a new sub-national index of women's empowerment using widely-available DHS data that has the potential to be used in many developing countries across the world. Prior work on examining female empowerment has been exclusively at the national level. The sub-national nature of FEMI demonstrates how national-only measures can actually obscure important sub-national differences in empowerment, as is the case for Nigeria. The country has strong state and regional variation across multiple aspects of women's empowerment, illustrating the importance of considering state and regional variation in addition to national variation. Our implementation makes

a strong case for the need for sub-national reporting of women's empowerment in addition to national measures.

We have demonstrated empirically that matters are much worse in the North than the South of Nigeria. In several aspects of women's empowerment, the North is worsening even as the South improves, particularly in education, decision making, and access to prenatal care. Even in categories where both the North and South are both showing improvement, the North still lags greatly behind. Targeted interventions may be needed to improve women's empowerment in the North so that all women in Nigeria have the levels of access to education, contraception, and the other opportunities enjoyed by women in the South.

Nationally, the FEMI improved considerably between 1990 and 2013. Despite the stark regional differences, women are better educated, have more opportunities for gainful employment, access to better reproductive healthcare, more decision making power in their families, and are encountering lower rates of physical and sexual violence. Access to contraception has actually fallen nationally; more research is needed to understand why this is the case.

While using DHS data does have some inherent limitations such as the necessity of estimating data for earlier surveys, the ability to examine women's empowerment sub-nationally is a major strength. FEMI and its individual category results represent large improvements in what is known about women's empowerment in Nigeria in terms of scope, within-country variation, and change over time.

We have successfully implemented FEMI in Nigeria and the methodology used could easily be extended to other countries. This would allow for between-country comparison as well as within-country variation. While different measures will continue to be computed based on needs and perceptions of women's empowerment, FEMI's sub-national contribution is unique and its wide scope of categories broaden its utility relative to existing measures.

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Chapter 1 Appendix

Table A1.1: FEMI, Violence Against Women, Employment, and inequality-adjusted Employment, by year and state.

Year	State	FEMI	Violence Against Women	Employment	Employment (inequality-adjusted)
1990	Abia	0.43	0.62	0.47	0.31
1990	Adamawa	0.26	0.35	0.41	0.29
1990	Akwa Ibom	0.40	0.59	0.45	0.30
1990	Anambra	0.49	0.61	0.52	0.39
1990	Bauchi	0.17	0.21	0.38	0.23
1990	Bayelsa	0.30	0.46	0.50	0.37
1990	Benue	0.34	0.39	0.51	0.37
1990	Borno	0.19	0.29	0.41	0.29
1990	Cross River	0.34	0.52	0.43	0.27
1990	Delta	0.47	0.58	0.53	0.41
1990	Ebonyi	0.29	0.53	0.48	0.34
1990	Edo	0.55	0.69	0.50	0.36
1990	Ekiti	0.38	0.63	0.53	0.38
1990	Enugu	0.41	0.58	0.43	0.26
1990	Federal Capital Territory	0.59	0.74	0.47	0.33
1990	Gombe	0.21	0.35	0.37	0.23
1990	Imo	0.45	0.63	0.48	0.33
1990	Jigawa	0.16	0.25	0.45	0.27
1990	Kaduna	0.23	0.32	0.41	0.24
1990	Kano	0.19	0.31	0.49	0.36
1990	Katsina	0.18	0.28	0.49	0.35
1990	Kebbi	0.21	0.28	0.54	0.53
1990	Kogi	0.36	0.58	0.51	0.39
1990	Kwara	0.45	0.71	0.61	0.51
1990	Lagos	0.60	0.77	0.64	0.54
1990	Nassarawa	0.28	0.40	0.45	0.31
1990	Niger	0.32	0.60	0.44	0.29
1990	Ogun	0.53	0.73	0.69	0.67
1990	Ondo	0.49	0.68	0.54	0.42
1990	Osun	0.53	0.75	0.60	0.52
1990	Oyo	0.54	0.74	0.69	0.66
1990	Plateau	0.26	0.40	0.42	0.28
1990	Rivers	0.37	0.54	0.45	0.29
1990	Sokoto	0.17	0.26	0.46	0.37
1990	Taraba	0.27	0.43	0.46	0.35
1990	Yobe	0.17	0.26	0.47	0.36
1990	Zamfara	0.18	0.31	0.50	0.37
1999	Abia	0.59	0.78	0.48	0.34
1999	Adamawa	0.35	0.35	0.52	0.40
1999	Akwa Ibom	0.50	0.52	0.60	0.57
1999	Anambra	0.63	0.73	0.67	0.56
1999	Bauchi	0.16	0.21	0.21	0.07
1999	Bayelsa	0.47	0.52	0.71	0.60

Year	State	FEMI	Violence Against Women	Employment	Employment (inequality-adjusted)
1999	Benue	0.41	0.49	0.46	0.31
1999	Borno	0.24	0.34	0.25	0.17
1999	Cross River	0.51	0.54	0.67	0.62
1999	Delta	0.60	0.67	0.66	0.63
1999	Ebonyi	0.42	0.66	0.43	0.32
1999	Edo	0.59	0.67	0.58	0.56
1999	Ekiti	0.58	0.75	0.65	0.56
1999	Enugu	0.56	0.66	0.63	0.49
1999	Federal Capital Territory	0.47	0.59	0.55	0.35
1999	Gombe	0.20	0.27	0.19	0.01
1999	Imo	0.60	0.75	0.44	0.32
1999	Jigawa	0.12	0.30	0.21	0.00
1999	Kaduna	0.25	0.47	0.09	0.00
1999	Kano	0.19	0.37	0.18	0.00
1999	Katsina	0.17	0.32	0.26	0.09
1999	Kebbi	0.14	0.26	0.31	0.18
1999	Kogi	0.47	0.64	0.56	0.44
1999	Kwara	0.57	0.82	0.68	0.51
1999	Lagos	0.70	0.82	0.77	0.79
1999	Nassarawa	0.40	0.47	0.59	0.47
1999	Niger	0.37	0.68	0.42	0.18
1999	Ogun	0.59	0.69	0.87	0.93
1999	Ondo	0.60	0.77	0.73	0.76
1999	Osun	0.62	0.84	0.62	0.60
1999	Oyo	0.64	0.78	0.71	0.77
1999	Plateau	0.41	0.57	0.47	0.24
1999	Rivers	0.55	0.62	0.61	0.51
1999	Sokoto	0.12	0.29	0.17	0.01
1999	Taraba	0.33	0.38	0.51	0.39
1999	Yobe	0.16	0.29	0.28	0.10
1999	Zamfara	0.14	0.27	0.27	0.11
2003	Abia	0.55	0.83	0.24	0.09
2003	Adamawa	0.31	0.25	0.53	0.53
2003	Akwa Ibom	0.43	0.45	0.45	0.45
2003	Anambra	0.59	0.76	0.52	0.39
2003	Bauchi	0.20	0.14	0.48	0.41
2003	Bayelsa	0.45	0.52	0.58	0.47
2003	Benue	0.36	0.45	0.38	0.33
2003	Borno	0.31	0.31	0.53	0.53
2003	Cross River	0.49	0.52	0.57	0.56
2003	Delta	0.55	0.66	0.56	0.49
2003	Ebonyi	0.37	0.69	0.16	0.05
2003	Edo	0.49	0.60	0.45	0.40
2003	Ekiti	0.58	0.75	0.56	0.38
2003	Enugu	0.51	0.67	0.51	0.34
2003	Federal Capital Territory	0.31	0.40	0.56	0.43
2003	Gombe	0.24	0.16	0.45	0.32
2003	Imo	0.56	0.79	0.17	0.05

Year	State	FEMI	Violence Against Women	Employment	Employment (inequality-adjusted)
2003	Jigawa	0.15	0.26	0.44	0.27
2003	Kaduna	0.36	0.51	0.41	0.35
2003	Kano	0.24	0.34	0.38	0.19
2003	Katsina	0.27	0.30	0.63	0.63
2003	Kebbi	0.21	0.21	0.68	0.68
2003	Kogi	0.45	0.58	0.54	0.54
2003	Kwara	0.54	0.77	0.68	0.57
2003	Lagos	0.64	0.79	0.67	0.66
2003	Nassarawa	0.37	0.41	0.62	0.62
2003	Niger	0.30	0.62	0.36	0.18
2003	Ogun	0.51	0.61	0.80	0.80
2003	Ondo	0.55	0.77	0.67	0.67
2003	Osun	0.55	0.83	0.46	0.37
2003	Oyo	0.58	0.74	0.56	0.56
2003	Plateau	0.40	0.56	0.44	0.29
2003	Rivers	0.53	0.62	0.46	0.37
2003	Sokoto	0.19	0.27	0.51	0.51
2003	Taraba	0.26	0.26	0.48	0.48
2003	Yobe	0.21	0.24	0.54	0.38
2003	Zamfara	0.22	0.22	0.65	0.65
2008	Abia	0.60	0.80	0.52	0.36
2008	Adamawa	0.33	0.57	0.37	0.37
2008	Akwa Ibom	0.60	0.70	0.63	0.56
2008	Anambra	0.60	0.81	0.39	0.20
2008	Bauchi	0.25	0.27	0.58	0.58
2008	Bayelsa	0.44	0.64	0.44	0.27
2008	Benue	0.46	0.48	0.72	0.70
2008	Borno	0.27	0.41	0.52	0.52
2008	Cross River	0.51	0.64	0.26	0.15
2008	Delta	0.52	0.66	0.49	0.33
2008	Ebonyi	0.44	0.57	0.61	0.61
2008	Edo	0.59	0.75	0.53	0.41
2008	Ekiti	0.63	0.75	0.62	0.58
2008	Enugu	0.48	0.62	0.32	0.17
2008	Federal Capital Territory	0.54	0.79	0.47	0.38
2008	Gombe	0.29	0.38	0.32	0.32
2008	Imo	0.63	0.82	0.47	0.33
2008	Jigawa	0.17	0.29	0.50	0.29
2008	Kaduna	0.35	0.51	0.31	0.19
2008	Kano	0.27	0.45	0.61	0.61
2008	Katsina	0.24	0.33	0.52	0.52
2008	Kebbi	0.26	0.43	0.49	0.49
2008	Kogi	0.52	0.61	0.52	0.52
2008	Kwara	0.51	0.74	0.67	0.57
2008	Lagos	0.69	0.89	0.66	0.55
2008	Nassarawa	0.44	0.66	0.33	0.23
2008	Niger	0.29	0.38	0.50	0.45
2008	Ogun	0.59	0.68	0.76	0.68

Year	State	FEMI	Violence Against Women	Employment	Employment (inequality-adjusted)
2008	Ondo	0.51	0.76	0.27	0.14
2008	Osun	0.65	0.83	0.64	0.63
2008	Oyo	0.61	0.76	0.81	0.81
2008	Plateau	0.41	0.56	0.24	0.13
2008	Rivers	0.54	0.70	0.40	0.33
2008	Sokoto	0.22	0.37	0.60	0.60
2008	Taraba	0.36	0.54	0.45	0.44
2008	Yobe	0.22	0.48	0.43	0.43
2008	Zamfara	0.22	0.42	0.40	0.34
2013	Abia	0.66	0.79	0.57	0.46
2013	Adamawa	0.37	0.56	0.47	0.39
2013	Akwa Ibom	0.57	0.73	0.56	0.47
2013	Anambra	0.66	0.80	0.53	0.42
2013	Bauchi	0.23	0.28	0.42	0.25
2013	Bayelsa	0.45	0.63	0.58	0.45
2013	Benue	0.49	0.52	0.77	0.76
2013	Borno	0.28	0.66	0.26	0.09
2013	Cross River	0.53	0.61	0.52	0.36
2013	Delta	0.57	0.76	0.51	0.39
2013	Ebonyi	0.50	0.62	0.55	0.48
2013	Edo	0.61	0.77	0.59	0.48
2013	Ekiti	0.70	0.83	0.62	0.59
2013	Enugu	0.64	0.76	0.58	0.52
2013	Federal Capital Territory	0.58	0.77	0.56	0.42
2013	Gombe	0.22	0.37	0.33	0.14
2013	Imo	0.67	0.84	0.49	0.37
2013	Jigawa	0.21	0.36	0.57	0.38
2013	Kaduna	0.45	0.55	0.60	0.47
2013	Kano	0.29	0.54	0.58	0.51
2013	Katsina	0.30	0.50	0.66	0.57
2013	Kebbi	0.24	0.40	0.60	0.58
2013	Kogi	0.57	0.77	0.63	0.59
2013	Kwara	0.62	0.84	0.64	0.55
2013	Lagos	0.73	0.90	0.72	0.62
2013	Nassarawa	0.49	0.64	0.57	0.48
2013	Niger	0.37	0.56	0.69	0.51
2013	Ogun	0.67	0.83	0.81	0.81
2013	Ondo	0.62	0.74	0.66	0.62
2013	Osun	0.67	0.85	0.70	0.62
2013	Oyo	0.65	0.77	0.77	0.77
2013	Plateau	0.46	0.61	0.44	0.26
2013	Rivers	0.65	0.77	0.70	0.63
2013	Sokoto	0.19	0.40	0.46	0.34
2013	Taraba	0.35	0.45	0.49	0.29
2013	Yobe	0.24	0.52	0.39	0.24
2013	Zamfara	0.25	0.45	0.66	0.55

Table A1.2: Education, inequality-adjusted Education, Reproductive Healthcare, Decision Making, and Access to Contraceptives, by year and state.

Year	State	Education	Education (inequality-adjusted)	Reproductive Healthcare	Decision Making	Access to Contraceptives
1990	Abia	0.40	0.23	0.81	0.51	0.12
1990	Adamawa	0.19	0.06	0.54	0.25	0.06
1990	Akwa Ibom	0.36	0.18	0.66	0.50	0.19
1990	Anambra	0.50	0.37	0.84	0.42	0.29
1990	Bauchi	0.07	0.01	0.27	0.22	0.08
1990	Bayelsa	0.30	0.13	0.27	0.42	0.17
1990	Benue	0.22	0.07	0.61	0.31	0.28
1990	Borno	0.10	0.02	0.35	0.20	0.00
1990	Cross River	0.32	0.14	0.55	0.43	0.11
1990	Delta	0.45	0.27	0.72	0.41	0.40
1990	Ebonyi	0.16	0.04	0.47	0.36	0.00
1990	Edo	0.60	0.49	0.69	0.44	0.62
1990	Ekiti	0.33	0.14	0.69	0.40	0.04
1990	Enugu	0.38	0.20	0.74	0.41	0.24
1990	Federal Capital Territory	0.75	0.75	0.92	0.48	0.33
1990	Gombe	0.11	0.03	0.34	0.28	0.06
1990	Imo	0.39	0.22	0.85	0.52	0.17
1990	Jigawa	0.04	0.01	0.23	0.20	0.00
1990	Kaduna	0.14	0.03	0.41	0.23	0.12
1990	Kano	0.05	0.01	0.23	0.19	0.04
1990	Katsina	0.03	0.00	0.21	0.21	0.00
1990	Kebbi	0.03	0.00	0.21	0.21	0.00
1990	Kogi	0.21	0.06	0.62	0.42	0.09
1990	Kwara	0.30	0.14	0.75	0.35	0.24
1990	Lagos	0.61	0.47	0.83	0.45	0.51
1990	Nassarawa	0.19	0.06	0.45	0.30	0.18
1990	Niger	0.19	0.08	0.60	0.31	0.06
1990	Ogun	0.34	0.17	0.84	0.41	0.34
1990	Ondo	0.44	0.26	0.82	0.40	0.33
1990	Osun	0.52	0.35	0.85	0.44	0.25
1990	Oyo	0.42	0.24	0.80	0.43	0.37
1990	Plateau	0.15	0.04	0.45	0.29	0.13
1990	Rivers	0.37	0.18	0.53	0.34	0.31
1990	Sokoto	0.05	0.01	0.21	0.19	0.00
1990	Taraba	0.10	0.02	0.54	0.31	0.00
1990	Yobe	0.04	0.01	0.18	0.23	0.00
1990	Zamfara	0.02	0.00	0.20	0.21	0.00
1999	Abia	0.64	0.57	0.89	0.62	0.34
1999	Adamawa	0.35	0.18	0.58	0.34	0.25
1999	Akwa Ibom	0.53	0.43	0.61	0.42	0.44
1999	Anambra	0.69	0.66	0.90	0.50	0.45
1999	Bauchi	0.09	0.01	0.28	0.23	0.13
1999	Bayelsa	0.54	0.50	0.37	0.47	0.39
1999	Benue	0.41	0.24	0.61	0.40	0.43
1999	Borno	0.26	0.14	0.42	0.23	0.12

Year	State	Education	Education (inequality-adjusted)	Reproductive Healthcare	Decision Making	Access to Contraceptives
1999	Cross River	0.57	0.45	0.58	0.45	0.42
1999	Delta	0.62	0.52	0.77	0.47	0.53
1999	Ebonyi	0.27	0.18	0.60	0.51	0.27
1999	Edo	0.66	0.56	0.72	0.43	0.59
1999	Ekiti	0.58	0.48	0.77	0.49	0.47
1999	Enugu	0.56	0.49	0.75	0.50	0.44
1999	Federal Capital Territory	0.57	0.41	0.67	0.36	0.44
1999	Gombe	0.23	0.11	0.40	0.24	0.14
1999	Imo	0.70	0.66	0.92	0.63	0.33
1999	Jigawa	0.03	0.00	0.18	0.18	0.06
1999	Kaduna	0.27	0.15	0.47	0.25	0.29
1999	Kano	0.19	0.07	0.34	0.19	0.19
1999	Katsina	0.15	0.05	0.28	0.24	0.05
1999	Kebbi	0.04	0.01	0.19	0.15	0.06
1999	Kogi	0.44	0.26	0.70	0.44	0.36
1999	Kwara	0.51	0.40	0.79	0.48	0.43
1999	Lagos	0.77	0.72	0.87	0.47	0.55
1999	Nassarawa	0.31	0.17	0.54	0.41	0.34
1999	Niger	0.30	0.15	0.56	0.31	0.33
1999	Ogun	0.39	0.26	0.78	0.50	0.40
1999	Ondo	0.47	0.30	0.80	0.49	0.49
1999	Osun	0.59	0.43	0.90	0.50	0.47
1999	Oyo	0.61	0.49	0.84	0.47	0.50
1999	Plateau	0.43	0.27	0.62	0.39	0.38
1999	Rivers	0.65	0.61	0.64	0.41	0.52
1999	Sokoto	0.06	0.01	0.20	0.16	0.03
1999	Taraba	0.23	0.11	0.45	0.37	0.25
1999	Yobe	0.14	0.03	0.28	0.20	0.08
1999	Zamfara	0.04	0.01	0.22	0.19	0.06
2003	Abia	0.73	0.67	0.92	0.64	0.16
2003	Adamawa	0.33	0.17	0.58	0.25	0.09
2003	Akwa Ibom	0.59	0.48	0.57	0.34	0.28
2003	Anambra	0.74	0.74	0.92	0.50	0.22
2003	Bauchi	0.10	0.03	0.31	0.23	0.07
2003	Bayelsa	0.64	0.62	0.42	0.46	0.20
2003	Benue	0.40	0.25	0.58	0.32	0.25
2003	Borno	0.34	0.21	0.48	0.25	0.10
2003	Cross River	0.67	0.54	0.59	0.43	0.29
2003	Delta	0.66	0.58	0.79	0.42	0.39
2003	Ebonyi	0.30	0.17	0.65	0.55	0.12
2003	Edo	0.63	0.51	0.74	0.34	0.35
2003	Ekiti	0.66	0.59	0.82	0.44	0.48
2003	Enugu	0.61	0.57	0.75	0.51	0.25
2003	Federal Capital Territory	0.35	0.14	0.51	0.15	0.23
2003	Gombe	0.29	0.16	0.46	0.22	0.09
2003	Imo	0.82	0.82	0.95	0.66	0.12
2003	Jigawa	0.02	0.00	0.17	0.17	0.00

Year	State	Education	Education (inequality-adjusted)	Reproductive Healthcare	Decision Making	Access to Contraceptives
2003	Kaduna	0.31	0.21	0.49	0.26	0.33
2003	Kano	0.26	0.11	0.42	0.18	0.17
2003	Katsina	0.19	0.07	0.31	0.26	0.02
2003	Kebbi	0.02	0.00	0.17	0.12	0.05
2003	Kogi	0.45	0.29	0.71	0.31	0.25
2003	Kwara	0.51	0.46	0.78	0.41	0.26
2003	Lagos	0.80	0.77	0.89	0.39	0.36
2003	Nassarawa	0.26	0.14	0.56	0.33	0.17
2003	Niger	0.24	0.10	0.50	0.18	0.21
2003	Ogun	0.37	0.22	0.75	0.45	0.21
2003	Ondo	0.43	0.24	0.78	0.45	0.37
2003	Osun	0.58	0.39	0.93	0.43	0.37
2003	Oyo	0.65	0.54	0.87	0.40	0.36
2003	Plateau	0.47	0.32	0.69	0.30	0.25
2003	Rivers	0.77	0.77	0.70	0.41	0.33
2003	Sokoto	0.03	0.01	0.19	0.15	0.00
2003	Taraba	0.19	0.08	0.37	0.27	0.12
2003	Yobe	0.18	0.06	0.37	0.18	0.03
2003	Zamfara	0.02	0.00	0.21	0.19	0.05
2008	Abia	0.79	0.79	0.82	0.61	0.22
2008	Adamawa	0.27	0.13	0.44	0.42	0.07
2008	Akwa Ibom	0.68	0.63	0.63	0.62	0.47
2008	Anambra	0.80	0.80	0.90	0.57	0.31
2008	Bauchi	0.07	0.02	0.32	0.20	0.07
2008	Bayelsa	0.66	0.49	0.45	0.54	0.24
2008	Benue	0.37	0.20	0.60	0.57	0.25
2008	Borno	0.12	0.06	0.30	0.29	0.04
2008	Cross River	0.62	0.54	0.61	0.72	0.39
2008	Delta	0.66	0.54	0.68	0.64	0.29
2008	Ebonyi	0.40	0.29	0.65	0.48	0.06
2008	Edo	0.72	0.68	0.87	0.58	0.25
2008	Ekiti	0.76	0.71	0.83	0.66	0.26
2008	Enugu	0.64	0.59	0.70	0.59	0.20
2008	Federal Capital Territory	0.63	0.53	0.72	0.45	0.36
2008	Gombe	0.20	0.10	0.40	0.41	0.15
2008	Imo	0.83	0.83	0.92	0.67	0.21
2008	Jigawa	0.03	0.00	0.24	0.17	0.01
2008	Kaduna	0.40	0.25	0.46	0.44	0.24
2008	Kano	0.21	0.09	0.33	0.11	0.05
2008	Katsina	0.02	0.00	0.19	0.32	0.04
2008	Kebbi	0.13	0.06	0.25	0.23	0.10
2008	Kogi	0.52	0.35	0.74	0.70	0.21
2008	Kwara	0.41	0.35	0.59	0.43	0.36
2008	Lagos	0.82	0.77	0.88	0.62	0.44
2008	Nassarawa	0.43	0.26	0.62	0.63	0.26
2008	Niger	0.12	0.04	0.37	0.41	0.09
2008	Ogun	0.58	0.57	0.79	0.58	0.23
2008	Ondo	0.66	0.57	0.65	0.65	0.29

Year	State	Education	Education (inequality-adjusted)	Reproductive Healthcare	Decision Making	Access to Contraceptives
2008	Osun	0.64	0.52	0.89	0.58	0.43
2008	Oyo	0.57	0.47	0.78	0.57	0.27
2008	Plateau	0.43	0.28	0.60	0.68	0.20
2008	Rivers	0.76	0.70	0.61	0.56	0.31
2008	Sokoto	0.06	0.01	0.20	0.10	0.04
2008	Taraba	0.32	0.18	0.45	0.38	0.15
2008	Yobe	0.08	0.03	0.27	0.12	0.02
2008	Zamfara	0.08	0.03	0.24	0.27	0.04
2013	Abia	0.83	0.80	0.88	0.62	0.42
2013	Adamawa	0.43	0.26	0.57	0.38	0.08
2013	Akwa Ibom	0.72	0.69	0.60	0.59	0.35
2013	Anambra	0.82	0.82	0.88	0.68	0.37
2013	Bauchi	0.16	0.07	0.44	0.26	0.09
2013	Bayelsa	0.66	0.51	0.42	0.43	0.30
2013	Benue	0.51	0.33	0.62	0.43	0.28
2013	Borno	0.26	0.16	0.41	0.26	0.07
2013	Cross River	0.64	0.54	0.64	0.68	0.38
2013	Delta	0.69	0.58	0.67	0.63	0.36
2013	Ebonyi	0.54	0.40	0.76	0.56	0.20
2013	Edo	0.72	0.62	0.80	0.61	0.37
2013	Ekiti	0.87	0.83	0.90	0.64	0.44
2013	Enugu	0.74	0.72	0.88	0.62	0.33
2013	Federal Capital Territory	0.71	0.61	0.77	0.51	0.39
2013	Gombe	0.22	0.11	0.45	0.16	0.11
2013	Imo	0.87	0.87	0.93	0.69	0.30
2013	Jigawa	0.05	0.01	0.33	0.18	0.02
2013	Kaduna	0.42	0.28	0.46	0.46	0.49
2013	Kano	0.25	0.11	0.44	0.10	0.02
2013	Katsina	0.11	0.04	0.28	0.35	0.06
2013	Kebbi	0.12	0.04	0.27	0.10	0.05
2013	Kogi	0.61	0.45	0.81	0.59	0.23
2013	Kwara	0.57	0.41	0.84	0.67	0.42
2013	Lagos	0.83	0.80	0.89	0.65	0.52
2013	Nassarawa	0.49	0.30	0.63	0.57	0.33
2013	Niger	0.29	0.15	0.54	0.30	0.14
2013	Ogun	0.54	0.49	0.83	0.65	0.38
2013	Ondo	0.71	0.60	0.72	0.61	0.40
2013	Osun	0.78	0.67	0.91	0.55	0.43
2013	Oyo	0.59	0.53	0.77	0.61	0.43
2013	Plateau	0.54	0.42	0.59	0.62	0.26
2013	Rivers	0.77	0.71	0.65	0.73	0.42
2013	Sokoto	0.07	0.01	0.23	0.07	0.04
2013	Taraba	0.31	0.17	0.48	0.52	0.22
2013	Yobe	0.16	0.11	0.34	0.18	0.03
2013	Zamfara	0.09	0.03	0.23	0.14	0.09

Table A1.3: National FEMI and category scores for Nigeria, by year.

Year	FEMI	Violence Against Women	Employment	Employment (inequality-adjusted)	Education	Education (inequality-adjusted)	Reproductive Healthcare	Decision Making	Access to Contraceptives
1990	0.35	0.49	0.50	0.38	0.26	0.15	0.54	0.33	0.18
1999	0.42	0.55	0.47	0.37	0.40	0.30	0.58	0.37	0.33
2003	0.41	0.52	0.51	0.44	0.43	0.34	0.60	0.33	0.21
2008	0.44	0.59	0.52	0.45	0.44	0.36	0.56	0.46	0.21
2013	0.48	0.64	0.59	0.49	0.49	0.41	0.61	0.46	0.27

Chapter 2: Women's empowerment in sub-Saharan Africa

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Abstract

Women's empowerment is a fundamental human right and a key aspect of at least five of the United Nations Sustainable Development Goals. Attempts to measure progress in this area have been limited by only using national level, and sometimes inadequate data. We used data from 142 nationally representative surveys for 39 countries to compute scores for six empowerment domains (Intimate Partner Violence, Access to Family Planning, Reproductive Healthcare, Employment, Education, and Decision-Making) for first-level subdivisions of all countries in Sub-Saharan Africa for three years (1995, 2005 and 2015). We combined the scores for these domains into the Female Empowerment Index (FEMI). The median scores for each domain increased by 0.09-0.13 over this period, except for Employment, which had a decrease of 0.02, and for Decision-Making, which increased by 0.15. The median FEMI score increased from 0.44 to 0.53. There was considerable geographic and temporal variation between countries and within many countries. We found a coastal-inland and north-south gradient within all domains other than employment. Geographic inequality was highest in Education, with the 10th percentile score at 0.07 and the 90th percentile at 0.88 in 2015. Our approach allows for an expanded understanding of

subnational and national variation and trends of women's empowerment that should be instrumental in efforts to improve women's lives.

Significance Statement

Women's empowerment is a human right and has been shown to improve entire communities. Previous work has typically been limited to a single topic, studied nationally, and/or examined over one time period. We have improved greatly upon these efforts by exploring six empowerment domains (intimate partner violence, family planning, reproductive healthcare, employment, education, and decision-making) and an empowerment index for sub-Saharan Africa (SSA) in 1995, 2005, and 2015. Empowerment is increasing, but the progress is uneven between domains and regions. We discovered worsening inequality within education and employment, and no progress in family planning access in northern SSA. These issues merit attention as they are a focus of attention and funding and key parts of the UN's Sustainable Development Goals.

Introduction

Gender equality is a fundamental human right and it is a component of several categories of the United Nations Sustainable Development Goals (SDGs; Gates, 2014; United Nations, 2014). Women's empowerment can be defined as the expansion of women's ability to make strategic life choices in a context where this was previously denied (Kabeer, 1999). Women's empowerment has been shown to be beneficial to entire families (Klasen & Lamanna, 2009) – empowerment is linked to improved child nutrition (Quisumbing et al., 1996), higher food security (Sraboni et al., 2014), and lower child morbidity and mortality rates (Gakidou et al., 2010; Knippenberg et al., 2005).

To better understand opportunities for and obstacles to improving women's empowerment, we need to measure how empowerment changes over time and space and what drives these changes. Past efforts to quantify empowerment have mostly relied on data that was readily available but not always relevant to the lives of everyday women, such as the proportion of members of parliament that are female (Klasen, 2006; Klasen & Schüler, 2011). Moreover, these efforts used mostly national-level data, which can hide important within-country variation (Graetz et al., 2018; Hellwig & Hijmans, 2017; Rettig et al., 2020).

Here we examine subnational variation in female empowerment across Sub-Saharan Africa (SSA) for three years (1995, 2005, and 2015) using data from 142 Demographic and Health System (DHS) surveys(ICF International, n.d.), with a total of 2,220,919 individual respondents. We measured women's empowerment in six key domains: Intimate Partner Violence (IPV), Access to Family Planning, Access to Reproductive Healthcare, Employment, Education, and Decision-Making (women's ability to decide whether they visit family, obtain healthcare, etc.) For each domain, scores between 0 (lowest possible empowerment) and 1 (highest possible empowerment) were computed based on the answers to one or more survey questions (Table S1). Employment and Education were adjusted for the inequality of women relative to men. We averaged the domain scores to compute the Female Empowerment Index (FEMI) to summarize trends in women's empowerment in SSA.

Materials and Methods

Overview

We compiled all available DHS Standard Survey data for countries in sub-Saharan Africa as well as DHS Continuous Survey data for Senegal that were available as of October 2020 (ICF, 1989-2019; Table S3). The Burundi 1987 survey was not used because data were not available for administrative subdivisions. We were unable to obtain access to the surveys for Eritrea and some of the surveys for Equatorial Guinea and South Africa.

The empowerment domains were created by grouping related questions or groups of questions on different topics (Table S1). All responses were standardized to binary answers with zero representing disempowerment and one representing empowerment, except for the Reproductive Healthcare and Employment domains, which have additional intermediate values between zero and one.

For each survey, responses from individual women were aggregated to the first administrative level below the country level (such as “states” or “provinces”). Some surveys, particularly early ones, used custom regions or regions that do not match current first administrative level boundaries. In these cases, we used interpolation to estimate the values for the current first administrative level areas (Hellwig & Hijmans, 2017; Rettig et al., 2020).

For the sexual violence category and the Reproductive Health and Education domains, we assessed the possibility of age-cohort effects due to the large age range of the survey (e.g. a woman aged 49 who was married at age 16 was married 33 years before the survey, and her experience may not reflect the experiences of younger women as attitudes and practices change). We found that the results were very similar results for women aged 18-30 versus women aged 18-49 when comparing the survey data (0.0, -

0.01, and +0.03, for sexual violence, Reproductive Health, and Education, respectively), so we opted to not restrict the sample by age in order to preserve a larger sample size.

Domain Computation

Intimate Partner Violence (IPV)

The IPV domain has two equally weighted categories: physical violence and sexual violence. For physical violence, we used five questions where women say whether it is acceptable for their partner to physically abuse them in different circumstances (e.g., "Do you believe beating is justified if the respondent argues with her partner?"; Table S1). Sexual violence is indicated by adolescent marriage because it indicates a lack of sexual decision-making power and because childhood marriage is considered sexual violence in and of itself (Nour, 2006).

It should be noted that DHS surveys include questions on women's direct experience with physical and sexual violence. However, prior research showed that these direct indicators are substantially lower than reported rates from other surveys (Antai & Antai, 2008; Oyediran & Isiugo-Abanihe, 2005; Rettig et al., 2020), possibly due to respondents being hesitant to report on potentially traumatic or sensitive topics to a stranger (Oyediran & Feyisetan, 2017). Because of this, we opted for assessing attitudes towards IPV to represent physical violence rather than its direct incidence.

Employment

The employment domain examines both the regularity of work and the type of payment received (Phan, 2016). We consider both formal and informal work, the latter of which is an important source of income for lower-income women (Cueva Beteta, 2006).

For regularity of work, respondents are assigned a 1 if they reported having year-round employment, 0.5 if they reported part-time or seasonal employment, and 0 if they had no employment. The pay portion of the domain assigns respondents 1 if they were paid in cash, 0.75 if they were paid a mixture of cash and in-kind payments, 0.5 if they were paid only in in-kind payments, and 0 if they were not paid. The results of these questions were then averaged and aggregated for women and men separately.

The Employment (and Education) domains were adjusted for inequalities between men and women by multiplying the woman's score by the inequality ratio (the woman's score divided by the men's score). This lowers the adjusted score if men have higher scores than women but not if both men and women have low scores. In this way, the scores of poor areas where few people of either gender may be employed or educated are not affected, but the scores are affected for areas with true inequality, where men are employed or educated at higher rates than women.

Education

The education domain is the average of two scores: the proportion of women who have completed at least six years of schooling, and the proportion who can read a simple paragraph in their native language without difficulty. The education domain is adjusted identically to the employment domain to help distinguish between regions where there is little schooling from truly unequal regions.

Reproductive Healthcare

The Reproductive Healthcare domain assesses whether mothers and their children receive adequate healthcare services and whether women had children as adolescents,

which is associated with higher mortality and morbidity rates (Nour, 2006). The World Health Organization recommends that all pregnant women receive four antenatal visits carried out by a trained worker, that children are delivered in a professional setting, and that infants have at least one postnatal visit within two months after birth (Dahiru & Oche, 2015).

For the antenatal care, child delivery, and postnatal care questions, we counted all children born within three years of the date of the interview. The adolescent childbearing, delivery, and postnatal visit categories were calculated in the standard fashion (that is, with 0 representing disempowerment and 1 representing empowerment). Antenatal visits were calculated using intermediate values to represent women who had some care, but less than the recommended amount of care: women who had no professional antenatal visits were assigned a 0, women with between one and three visits a 0.5, and women with 4 or more visits a 1. The overall Reproductive Healthcare domain is the average of these four categories.

Decision-Making

For Decision-Making, we computed the average value of the answers to four questions (see Table S1). The domain score is the mean of the answers to these questions. For this domain, “self” and “self and partner” were both assigned a 1, representing empowerment, as the woman had a say in the decision-making for that question.

We included two less critical choices within the decision-making domain: whether women have a say in what to cook for dinner, and whether they have a say in household purchases (“large purchases” are addressed in a separate question). We

included these because even though the ability to make such choices may not greatly affect a woman's life, a lack of ability to make decisions over even basic choices clearly indicates disempowerment.

Access to Family Planning

The Access to Family Planning domain considers whether married women who do not wish to currently become pregnant are using modern contraceptives. DHS survey data include a pre-calculated version of access to family planning, which measures the proportion of married women who are currently using modern contraceptive methods. However, in many cases, calculations using the programming code released by DHS (Bradley and Croft 2017) that follows the methods of Bradley et al. (2012) do not match the already-calculated version (Rettig et al., 2020). We corrected the calculations, and we also changed the denominator from "all married women" to "married women who do not want a child at the time of the survey". Excluding married women who currently want children, and therefore do not need contraception, more accurately captures effective access for empowerment purposes.

Spatial and Temporal Estimation

To create yearly estimates at the first administrative level for every country in sub-Saharan Africa, we followed a three-step process. First, we estimated missing data at the first administrative level (“imputation”). Second, for surveys that did not use the first administrative level for their surveys, we downscaled the results to the first administrative level (“interpolation”). In a few cases, data were given at the second administrative level. In these cases, we aggregated them to the first administrative level

to ensure a large enough sample size for each area mapped. Finally, we used the corrected, standardized survey data to create estimates for 1995 through 2015 ("extrapolation"), although in this paper we focus on general trends by examining in detail the years 1995, 2005, and 2015.

Imputation

Although the DHS questions themselves are generally standardized, a given survey does not necessarily include all questions, particularly for earlier surveys. If questions were missing, we estimated them using Random Forest (Breiman, 2001), using standardized predictor variables that were available for all surveys (year, country, age at first marriage, age at first child, number of years of education, longitude and latitude, age at the time of the survey, and number of births in the last five years). For education questions, "number of years of education" was dropped as a predictor.

Two domains (education and employment) used adjustments in order to capture gender-based inequalities in these domains. In these cases, the men's domains were estimated separately from the women's, using the predictor variables of year, longitude, and latitude (other potential predictor variables for men were missing from one or more surveys).

The number of areas needing imputation varied by domain, ranging from less than 1% for Access to Family Planning to 26% for men's employment (Table S1). The Random Forest model R^2 values ranged from 0.56 in the case of men's employment to 0.84 for IPV and Education (Table S2). Once estimations for all domains were imputed, FEMI scores were calculated for each area as the arithmetic mean of the six domain scores.

Interpolation

DHS surveys generally include either geographic coordinates or information on the first administrative level where the survey was located. However, some surveys, particularly older ones, used different geographic boundaries (typically aggregations of multiple first administrative areas). In addition, in several countries, the subdivision boundaries changed over time. To standardize results, all values were calculated for the current first administrative areas for each country.

Interpolation was achieved in one of two ways. In the case where there was a survey before and after a non-standard survey, we used the year-weighted mean of the surveys immediately before and after the non-standard survey and applied a linear adjustment factor to ensure that the overall regional mean matched that of the original survey regions.

In the case where only there was only one predictor survey available, we first aggregated the first administrative level survey values based on what region it belonged to in the regional survey. Then, for each domain, we calculated the difference between the aggregated regions of the regional survey and the created regions of the first administrative level survey. These differences were then used to downscale the larger regions to the first administrative level areas. Additionally, there was one special case. In Mali, there were two surveys: one in 1987, and one in 2012, but the earlier survey was only done in the southern half of the country. In this case, we split the north and south and treated them as different countries for interpolation purposes.

Extrapolation

To estimate the yearly values for each first administrative level for each country, we used one of three methods, depending on the available survey data. If a survey was within 2 years of 1995, 2005, or 2015, we directly used the survey by reassigning it to the relevant year. In other cases, if there were two or more surveys, we used the linear trend to estimate values for each domain and year of interest. If there were no surveys or only one survey was available, we created a Random Forest model to predict values for each of the three years (Table S2). We used UN-reported Human Development Index and maternal mortality values as country-level predictors, and UN-adjusted population density and survey data where available as first administrative level predictors.

Assessment

To assess the amount of subnational variation between countries, we calculated the 10^{th} to 90^{th} percentile range of scores as well as median values within each country for each domain and FEMI. We then compared these values for each country. To assess the degree of association between FEMI and national level development indicators, we used linear regression models of FEMI in response to the Human Development Index, the Gender Development Index, the Gender Inequality Index, and log-scaled Gross Domestic Product per capita.

Results and Discussion

Continental patterns of empowerment

In 2015, the (population-weighted) median scores for the empowerment domains were between 0.34 (Education) and 0.66 (Reproductive Healthcare; Table 1). The score for four out of the six domains increased between 0.09 and 0.13 between 1995 and 2015. The Decision-Making score increased by 0.16, while the score for Employment decreased by 0.02. The FEMI increased by 20%, from 0.44 in 1995 to 0.53 in 2015.

Table 2.1. Median and 10th-90th percentile ranges (in parentheses) for six female empowerment domains and the Female Empowerment Index, for all women in SSA for three years (1995, 2005, and 2015).

	1995	2005	2015
Intimate Partner Violence	0.50 (0.28-0.72)	0.52 (0.30-0.77)	0.61 (0.42-0.83)
Employment	0.48 (0.32-0.64)	0.49 (0.27-0.68)	0.46 (0.32-0.68)
Family Planning	0.38 (0.14-0.71)	0.43 (0.21-0.76)	0.51 (0.19-0.81)
Education	0.24 (0.02-0.77)	0.25 (0.04-0.84)	0.34 (0.07-0.88)
Decision-Making	0.47 (0.23-0.57)	0.49 (0.22-0.74)	0.62 (0.25-0.87)
Reproductive Healthcare	0.56 (0.23-0.81)	0.58 (0.28-0.84)	0.66 (0.41-0.87)
FEMI	0.44 (0.26-0.65)	0.46 (0.31-0.70)	0.53 (0.33-0.77)

The decline in the Employment domain was due to worsening inequality between men and women in employment. Although a higher proportion of women had some form of employment in 2015 than in 1995 (0.56 vs 0.51), after adjusting for inequality, the median score dropped slightly, going from 0.48 to 0.46. In the other inequality-adjusted domain, Education, there was also an increase in inequality between 1995 and 2015. Completion of primary school went from a ratio of 9.5 women per 10 men in 1995 to 8.4 women per 10 men in 2015. Education was also the only domain where the median

value of 0.34 in 2015 (Table 1) was much lower than the mean value of 0.41. For all other domains, the difference between the median and mean scores were +/- 0.03.

Geographic inequality

In all empowerment domains except employment, there was a continental geographic gradient from north to south, showing increases southward. More inland regions also generally had lower scores than coastal regions, forming a T-shaped band of lower scores (Figures 2.1-2.3). These general patterns were relatively stable across domains and over time.

Geographic inequality was the highest in Education, with both the lowest 10th percentile (0.07) and the highest 90th percentile score (0.88) in 2015. It was also very high for Family Planning (0.19 to 0.81). Geographic inequality was least pronounced in employment, with a 10th percentile score of 0.32 and a 90th percentile score of 0.68 in 2015. Geographic variation in the FEMI increased between 1995 and 2015 because of the decline or small increase of domain scores in northern and inland areas, while they increased much more in southern and coastal SSA.

For all domains (except employment) there were marked geographical differences in the magnitude, or even the direction, of change over the period of study (Figures A2.1-2.2). For example, increases in the Decision-Making domain averaged 0.34 in southern SSA but only 0.03 in northern SSA. Access to Family Planning had remarkable gains in eastern Africa (e.g., Rwanda increased by 0.41, Ethiopia 0.39, and Malawi 0.38), but it decreased or remained stagnant in much of Central African and saw large declines in Sahelian west Africa. This stagnation and decline is despite numerous intervention efforts during the study period (Babalola et al., 2017; Lopez et al., 2016). It is not clear

whether these programs are too limited in scope, ineffective, or related to changing attitudes (i.e. fewer women desiring contraception). Additional survey data related to the reasons for contraception non-use could be used to clarify this trend (Blackstone et al., 2017).

Subnational variation

Within each country, we computed the median inter-quantile range for the 10^{th} to 90^{th} percentile scores as of 2015 to quantify the amount of subnational variation within each domain. The median difference (across countries) was between 0.10 (Decision-Making) and 0.18 (Education) for the six domains, and was 0.10 for the FEMI (Figure 2.4). Subnational variation was relatively low in southern Africa and especially high in Nigeria, Kenya, Ethiopia, Cameroon, and Uganda (Figures. 2.1-2.3). For example, in 2015, the inter-quantile range was 0.51 for Nigeria and 0.33 for Kenya.

Educational attainment is one of the most important factors influencing women's empowerment (Axinn & Barber, 2001; Larsen & Hollos, 2003; Phan, 2016). Even though it can be directly influenced through policy, it stood out for both high inequality between regions and overall low attainment, in part because of increasing gender inequality. The median inter-quantile range in education scores was 1.8 times greater than the median increase in educational attainment we observed over the past 20 years, signifying that within-country educational attainment is extremely heterogenous. Focus on national values may lead to inefficient policy and allocation of resources, while the explicit study of subnational variation may help shed more light on the processes that shape women's empowerment. For example, the northern parts of the Sahelian countries tend to be more alike one another compared to southern regions in the same

countries. This suggests that the processes that shaped empowerment in this region are partly independent of national policies and could be better understood by regional analysis. Additionally, a focus on broadening educational *per se* may be insufficient to solve regional and social educational inequalities. Programs intended to increase equitable access to education should address subnational inequalities and put additional emphasis on ensuring that girls are able to attend school(Lewin, 2009; Lucas & Mbiti, 2012).

Table 2.2. Association between female empowerment categories (Pearson's Correlation Coefficient) for the first-level administrative subdivisions for 39 countries in SSA, using the most recent survey data available for each country (n = 531,047).

	Intimate Partner Violence	Family Planning	Reproductive Healthcare	Employment	Education
Family Planning	0.54				
Reproductive Healthcare	0.70	0.62			
Employment	0.15	0.08	0.18		
Education	0.61	0.79	0.60	0.15	
Decision- Making	0.54	0.42	0.36	0.03	0.42

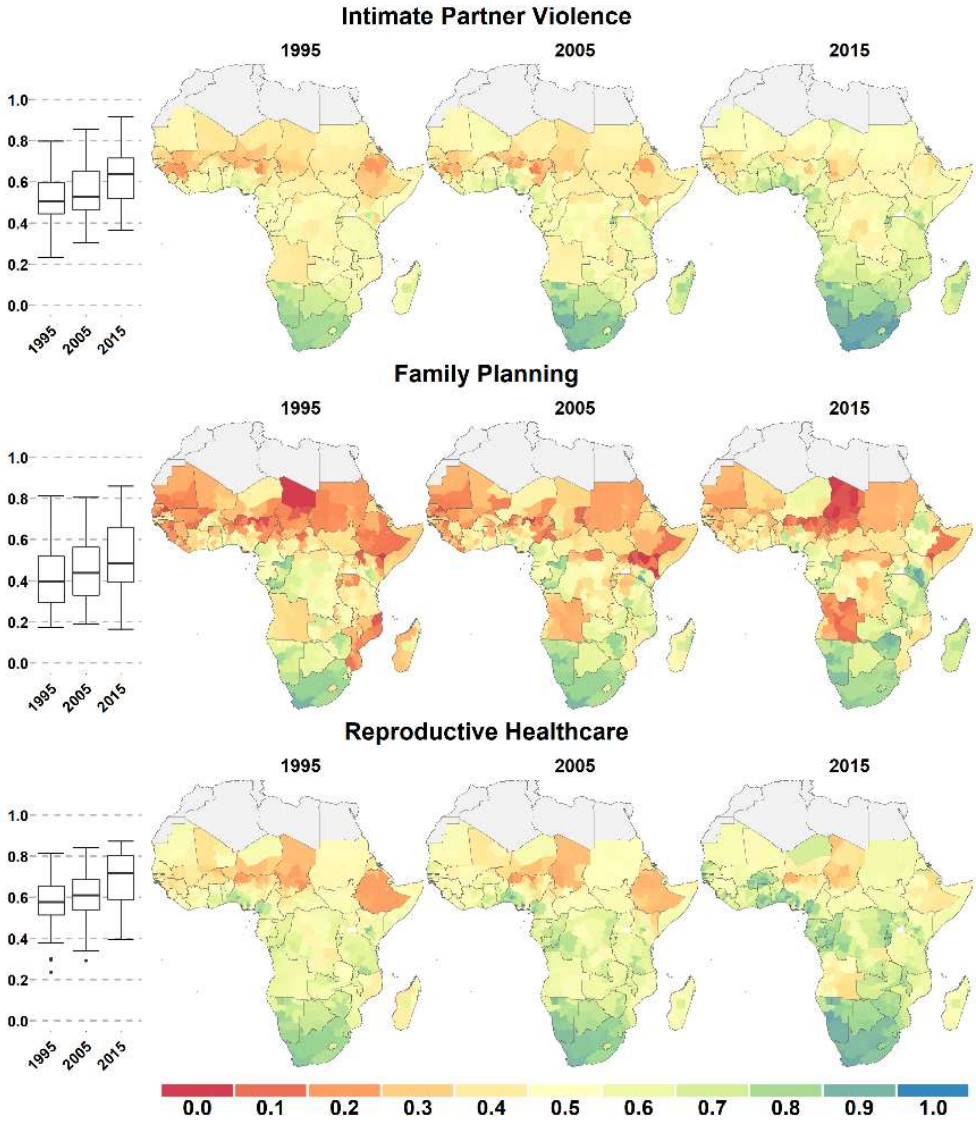

Figure 2.1. Scores for three female empowerment domains across Sub-Saharan Africa in 1995, 2005, and 2015. (a) Intimate Partner Violence, (b) Access to Family Planning, and (c) Access to reproductive healthcare. Scores can range from 0 (no empowerment) to 1 (full empowerment) and are shown for first-level administrative subdivisions. Boxplots (left) show the and quartiles of first-level administrative subdivision scores for each domain.

Interconnectedness of empowerment domains

We chose domains that are directly connected to important facets of empowerment, avoiding the use of proxies that complicate interpretation (to the greatest extent that was supported by data; see Methods). The domains reflect key opportunities that define

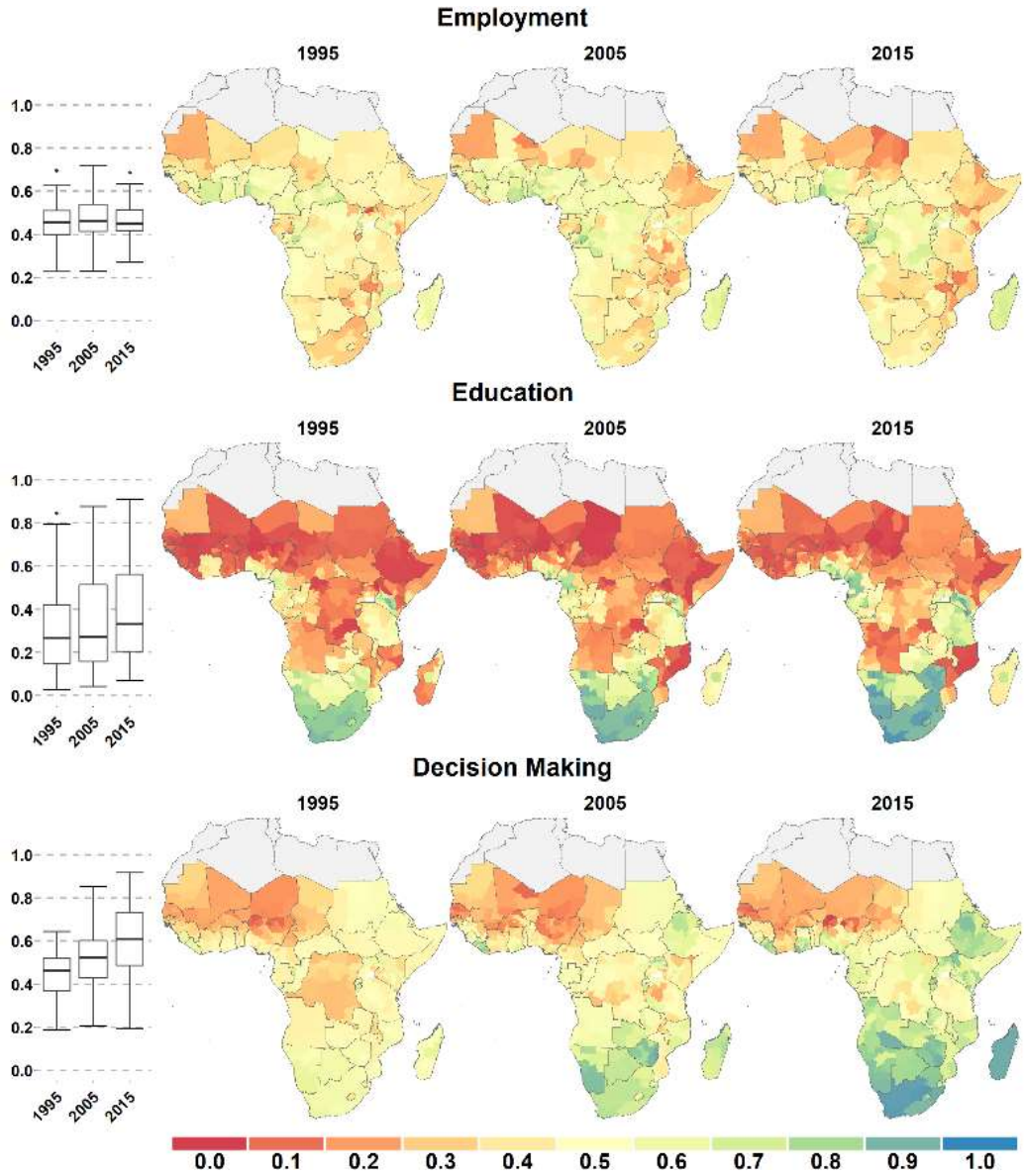

Figure 2.2. Scores for three female empowerment domains across Sub-Saharan Africa in 1995, 2005, and 2015. (a) Employment, (b) Education, and (c) Decision-Making, by first-level administrative subdivisions. Boxplots (left) show the range and quartiles of first-level administrative subdivision scores for each domain.

a woman's life (Kabeer, 1999) and include basic education and literacy, choosing whether and when to have children, marrying and having children as an adult, and accessing professional care during and after pregnancy. Additionally, disempowerment can be socially-mediated as well as structural, and part of the Intimate Partner Violence

domain tracks internalized disempowerment (Matheson et al., 2015; where women actively agree with their own disempowerment; Table S1).

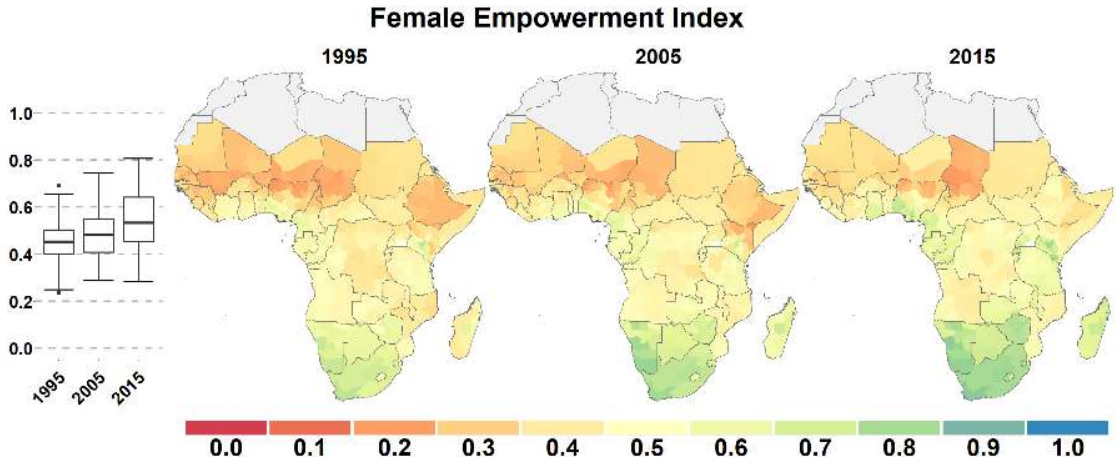

Figure 2.3. The Female Empowerment Index (FEMI) for first-level administrative areas in Sub-Saharan Africa in 1995, 2005, and 2015. Boxplots (left) show the and quartiles of first-level administrative subdivision scores for each domain.

It is important to note that many aspects of empowerment are not independent, and most domains have high correlations with one another (Table 2). These correlations match the findings of other studies. Improving women's access to education in the absence of access to high-quality employment for women limits the utility of such education, which makes families less likely to seek it out for their daughters (Klasen & Lamanna, 2009). Literacy has been linked to improved child health and access to reproductive healthcare(Sandiford et al., 1995), and although results are somewhat mixed, Employment has been shown to be linked to IPV (Terrazas-Carrillo & McWhirter, 2015; Vyas & Watts, 2009). Surprisingly, Employment was very weakly correlated with the other domains (0.03 to 0.18) and the correlation with Education was unexpectedly

low at 0.15. This may be because most employment was in the informal sector, where education may be less relevant, but further examination is warranted.

Association between FEMI and national-level indicators

The correlation coefficient between the FEMI and four prominent national-level indicators of wellbeing for the three years of the study was 0.70 for the Human Development Index (HDI), 0.79 for the Gender Development Index (GDI), and -0.71 for the Gender Inequality Index (GII) (Figure 2.5). The strong correlation of the FEMI with these indicators demonstrate that they capture the same broad patterns. The differences between these indices merit additional exploration, but their correlation suggests that the conceptual shortcomings of the variables chosen in these national-level indices may be less important than previously argued (Hirway & Mahadevia, 1996; Klasen, 2006; Klasen & Schüler, 2011; Raj, 2017). Future work could explore these associations by understanding patterns within data-rich countries to enable better estimations for data-poor countries.

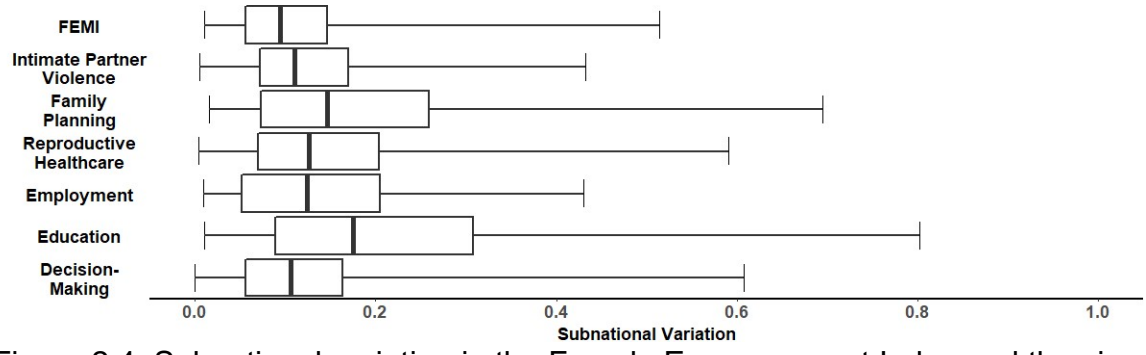

Figure 2.4. Subnational variation in the Female Empowerment Index and the six empowerment domains across 39 countries in SSA. Subnational variation for each country was expressed as the difference between the 10th and 90th percentile scores for first-level subdivisions. Boxplots express the range of variation between countries.

The effect of log-transformed GDP per capita on the FEMI was positive but small (Figure 2.5). While the slope of the regression line was essentially the same for the three years, the intercept was slightly higher for 2015. This suggests a very small improvement in FEMI for a given increase in GDP. Additionally, the correlation between the two variables decreased over time, with scores of 0.52 in 1995, 0.49 in 2005, and 0.41 in 2015. The weaker correlation of the FEMI with GDP suggests that while increasing wealth helps to improve women's empowerment in the poorest countries, this effect decreases as countries become wealthier. Importantly, it also suggests that a high GDP is not required to improve empowerment. When examining the linear regressions, the Sahelian countries generally had the largest negative model residuals for GDP, indicating that these countries have a noticeably lower FEMI than expected given the other national-level indices. In contrast, the southern African countries and Kenya do better than expected (Figure. A2.3).

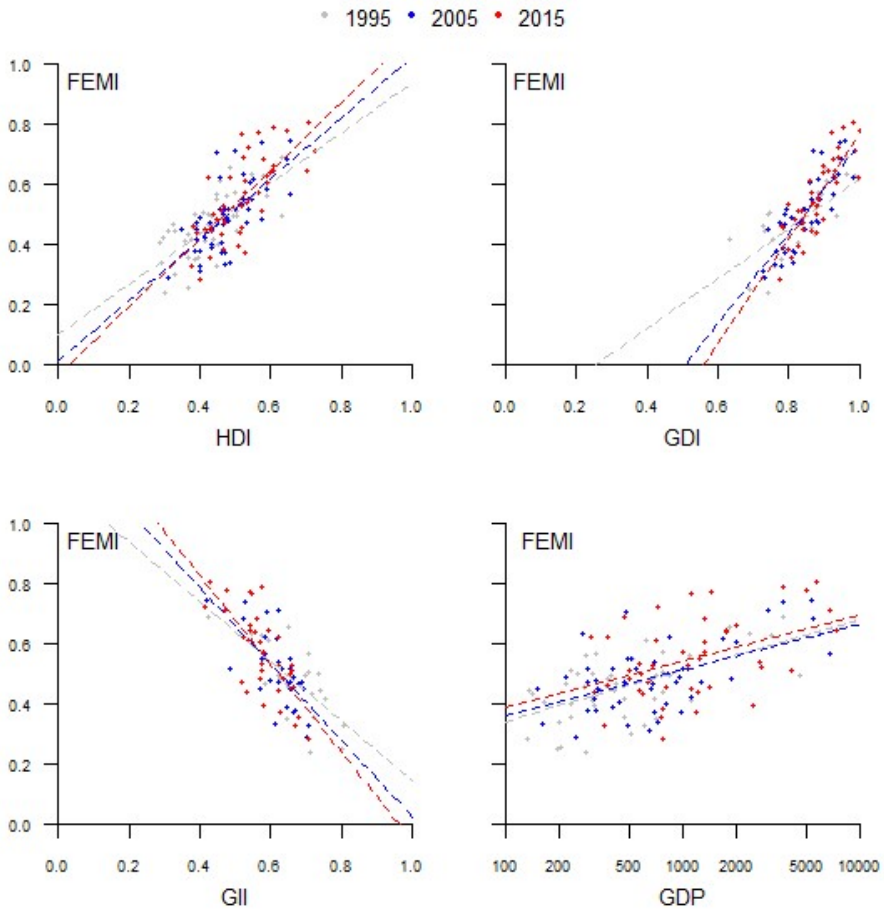

Figure 2.5. Relationship between the Human Development Index (HDI), the Gender Development Index (GDI), the Gender Inequality Index (GII), and Gross Domestic Product (GDP, log-scale) versus the Female Empowerment Index (FEMI) for countries in Sub-Saharan Africa in 1995, 2005, and 2015.

Implications for sustainable development

The Sustainable Development Goals (United Nations, 2014) provide a global focus on several aspects of international development, and research is desperately needed to assess progress towards these goals(Raj, 2017). Our methods can contribute to a better understanding of patterns of change within several of the SDGs. Target 3.7 (universal access to family planning) directly relates to the Access to Family Planning domain. The Reproductive Healthcare domain connects to target 5.6 (universal access

to reproductive health and rights), as well as targets 3.1 (reduce maternal mortality) and 3.2 (reduce infant and under-5 mortality) via the connection between maternal healthcare and maternal mortality ratio and child health (Alvarez et al., 2009; Roy & Shengelia, 2016). Goal 4's topic is universal and equitable education, which relates directly to the Education domain. Physical, sexual, and emotional violence (targets 5.1-5.3) are addressed in the IPV and Decision-Making domains. Employment is connected to target 8.5 (universal employment), and our results are also relevant for target 10.2 (socially, politically, and economically empower all people, regardless of personal characteristics).

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Chapter 2 Appendix

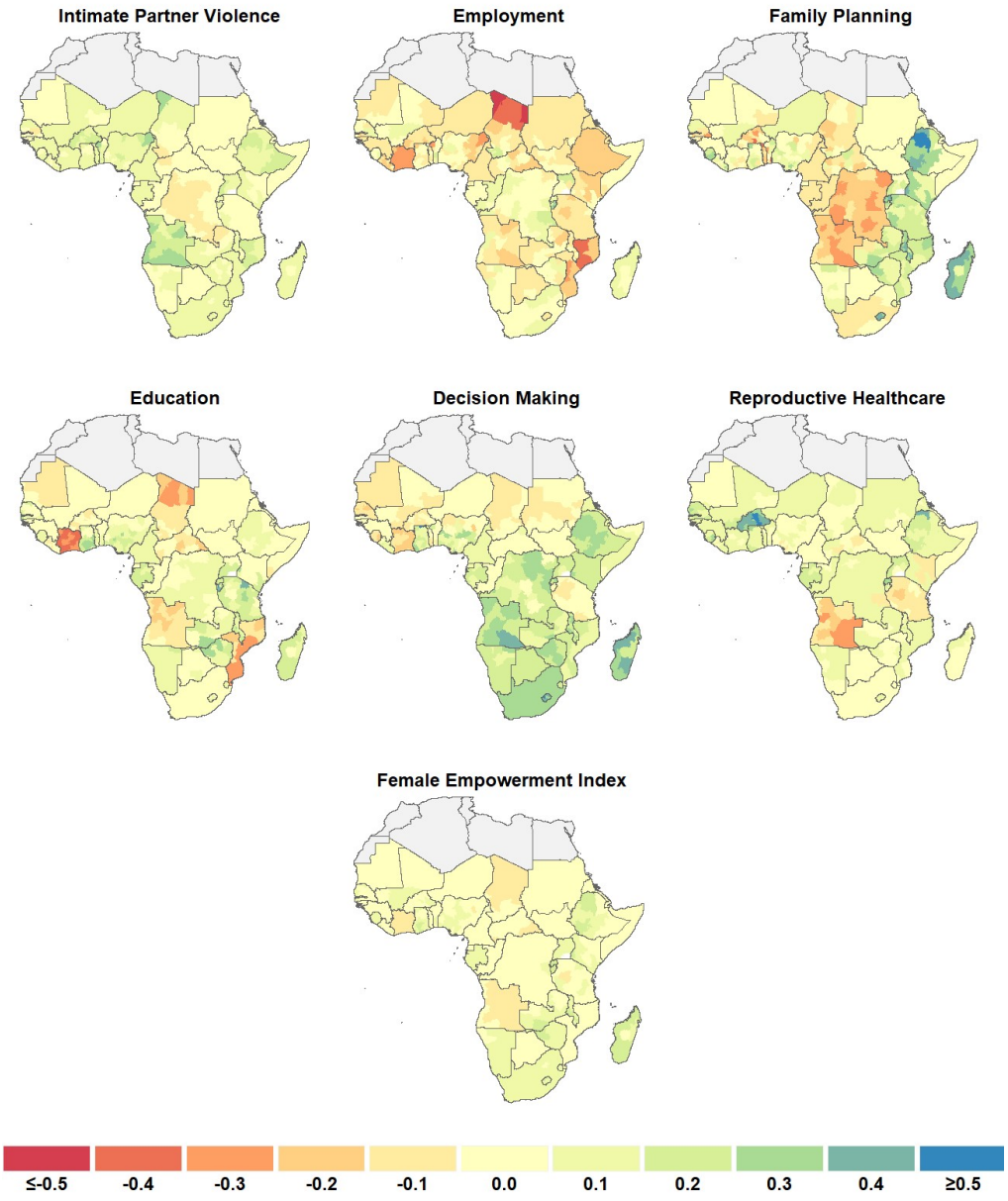

Figure A2.1. Change in Female Empowerment Index and Domain scores between 1995 and 2015 for first-level administrative-subdivisions in Sub Saharan African countries.

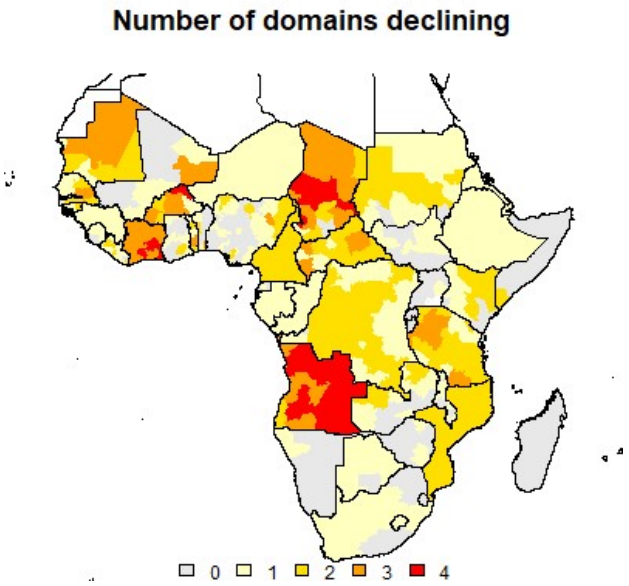

Figure A2.2. The number of domains experiencing a decline in value between 1995 and 2015, by first-level administrative subdivisions in Sub-Saharan African countries.

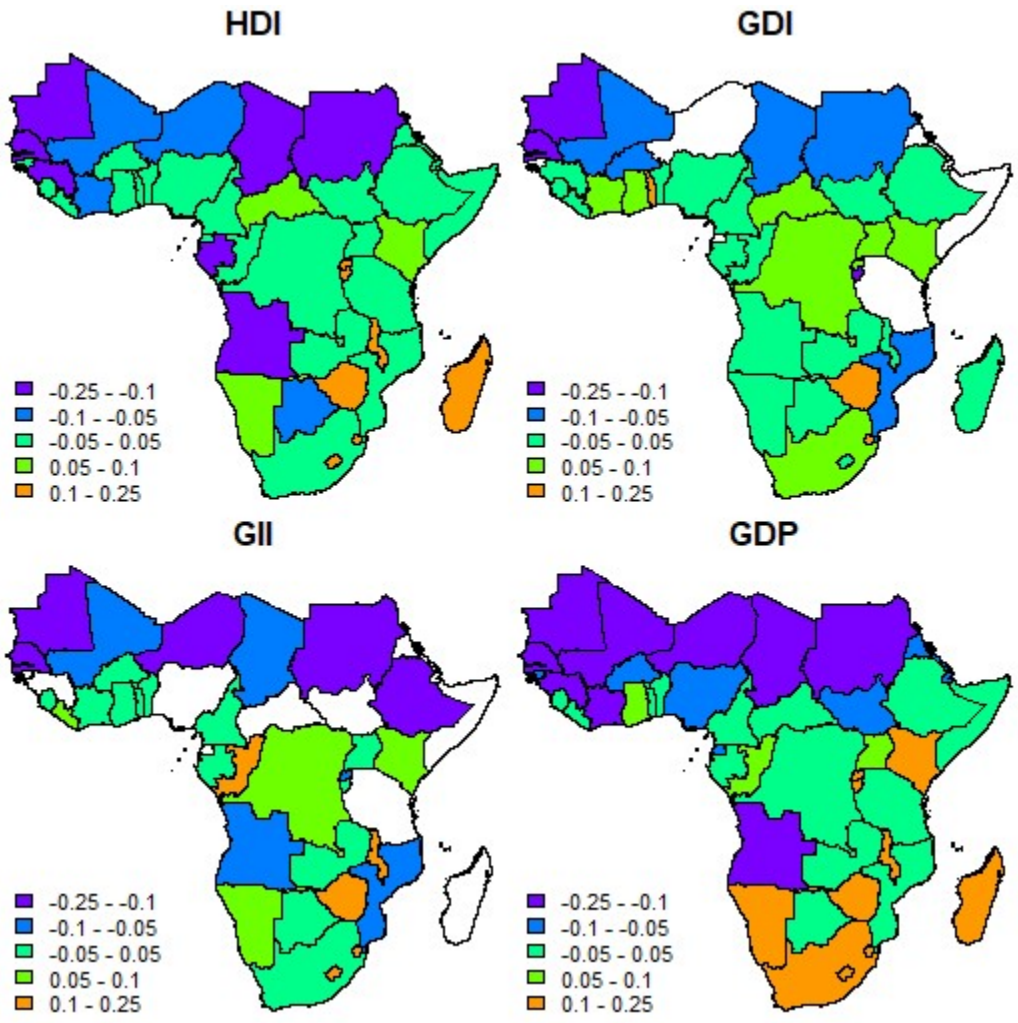

Figure A2.3. Model residuals for linear regression models of the Female Empowerment Index as a function of the Human Development Index (HDI), Gender Development Index (GDI) Gender Inequality Index (GDI), and the Gross Domestic Product GDP), for each country in sub-Saharan Africa in 2015. Countries colored in white indicate that the corresponding variable was not available for that country.

Table A2.1. Survey questions used and the range of possible values, by domain.

Domain	Question	Possible Values
Decision-Making	Does the respondent have a say in her health?	0.0, 1.0
	Does the respondent have a say in large purchases?	0.0, 1.0
	Does the respondent have a say in household purchases?	0.0, 1.0
	Does the respondent have a say in visits to family?	0.0, 1.0
	Does the respondent have a say in food to be cooked?	0.0, 1.0
	Does the respondent have a say in deciding what to do with money?	0.0, 1.0
Employment	Regularity of work: Did the respondent work all year, part of the year, or not at all?	0.0, 0.5, 1.0
	Type of pay: Was the respondent paid cash, mixed cash and in-kind payments, in-kind payments only, or not at all?	0.0, 0,5, 0.75, 1.0
Education	Did the respondent attend at least 6 years of school?	0.0, 1.0
	Can the respondent read a short paragraph shown to them?	0.0, 1.0
Intimate Partner Violence	Childhood marriage: Did the respondent get married before the age of 18?	0.0, 1.0
	Is beating justified if the respondent goes out without telling her partner?	0.0, 1.0
	Is beating justified if the respondent neglects the children?	0.0, 1.0
	Is beating justified if the respondent argues with her partner?	0.0, 1.0
	Is beating justified if the respondent refuses to have sex?	0.0, 1.0
	Is beating justified if the respondent burns the food?	0.0, 1.0
Reproductive Healthcare	How many prenatal visits did the respondent have for her children?	0.0, 0.5, 1.0*
	Did the respondent have a child before the age of 18?	0.0, 1.0
	Were the respondent's children delivered in a professional setting?	0.0, 1.0*
	Did the respondent have a postnatal visit for their children within two months after birth?	0.0, 1.0*
Family Planning	Is the respondent using modern contraception if they are married and do not currently desire more children?	0.0, 1.0

*Questions apply to each child born within three years of the survey date.

Table A2.2. Random Forest R^2 values for imputation, the fraction of first-level administrative subdivisions for which values were imputed, and Random Forest R^2 values for extrapolation, by first administrative area. N/As for men's employment and education extrapolation is because inequality adjustments were done before extrapolation. The FEMI was calculated after imputation so that all domains were available for each region, so no fraction is imputed for FEMI during extrapolation.

Domain	R^2 (Imputation)	Fraction Imputed	R^2 (Extrapolation)
Decision-Making	0.76	0.27	0.85
Employment (Women)	0.56	0.13	0.61
Employment (Men)	0.6	0.16	n/a
Education (Women)	0.87	0.25	0.89
Education (Men)	0.72	0.26	n/a
Intimate Partner Violence	0.84	0.26	0.83
Reproductive Healthcare	0.81	0.03	0.86
Family Planning	0.71	0	0.78
Female Empowerment Index	n/a*	n/a*	0.89

Table A2.3. Survey data used by country and year. All survey data were taken from Demographic and Health Surveys (https://dhsprogram.com/)

Country	Survey years
Angola	2015
Benin	1996, 2001, 2006, 2011, 2017
Botswana	-
Burkina Faso	1993, 1998, 2003, 2010
Burundi	2010, 2016
Cameroon	1991, 1998, 2004, 2011, 2018
Central African Republic	1994
Comoros	1996, 2012
Côte d'Ivoire	1994, 1998, 2011
Democratic Republic of the Congo	2007, 2013
Djibouti	-
Ethiopia	2000, 2005, 2011, 2016
Equatorial Guinea	-
Gabon	2000, 2012
Gambia	2013
Ghana	1988, 1993, 1998, 2003, 2008, 2014
Guinea	1999, 2005, 2012, 2018
Guinea-Bissau	-
Kenya	1989, 1993, 1998, 2003, 2008, 2014
Lesotho	2004, 2009, 2014
Liberia	1986, 2007, 2013
Madagascar	1992, 1997, 2003, 2008
Malawi	1992, 2000, 2004, 2010, 2015
Mali	1987, 1995, 2001, 2006, 2012, 2018
Mauritania	2000
Mozambique	1997, 2003, 2011
Namibia	1992, 2000, 2006, 2013
Niger	1992, 1998, 2006, 2012
Nigeria	1990, 1999, 2003, 2008, 2013, 2018
Republic Of Congo	2005, 2011
Rwanda	1992, 2000, 2005, 2010, 2014
São Tomé And Príncipe	2008
Senegal	1986, 1992, 1997, 2005, 2010, 2012, 2015, 2016-2019
Sierra Leone	2008, 2013, 2019
Somalia	-
South Africa	1998, 2016
South Sudan	-
Sudan	1989
Swaziland	2006

Tanzania	1991, 1996, 1999, 2004, 2010
Togo	1988, 1998, 2013
Uganda	1988, 1995, 2000, 2006, 2011, 2016
Zambia	1992, 1996, 2001, 2007, 2013
Zimbabwe	1988, 1994, 1999, 2005, 2010, 2015

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Chapter 3: Predictors of Women's Empowerment in Sub-Saharan Africa

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Abstract

Patterns of women's empowerment have been mapped, but the relation between empowerment and ecological, economic, and geographic factors is not well understood. We modeled country-level normalized Female Empowerment Index data for 2015 for all first-level administrative subdivisions in sub-Saharan Africa (SSA) as an effect of travel time to the nearest city, distance to the nearest coastline, GDP per capita (PPP), population density, annual temperature and rainfall. Models were made for the entire continent and four main regions in SSA (North/Western, Eastern, Central, and Southern). Only the North/Western and Eastern regions were different from the null model. Population density was consistently one of the most important predictors and showed a strong positive effect on women's empowerment even at relatively low densities. Distance to the coast was the second most important factor, with populations living within 100 km of the coastline having a positive association with empowerment and those living beyond 100 km a negative association. Of the remaining predictors, travel time to the nearest city, temperature, and GDP per capita were as important predictors in only two out of three models. Rainfall was not an important predictor within any model.

Introduction

The empowerment of women is important for its own sake and is also a major international development focus. Empowerment is featured within several the United Nations' Sustainable Development Goals (SDGs) (United Nations, 2014). Empowerment is commonly defined as the ability for women to make strategic choices in a context previously denied to them (Kabeer, 1999). Improving the empowerment of women has effects beyond their personal choices – improvements in women's empowerment can have positive effects on their spouses and children as well (Gakidou et al., 2010; Knippenberg et al., 2005; Sraboni et al., 2014).

There have been a few studies that have estimated aspects of empowerment at a subnational level (Bosco et al., 2017; Graetz et al., 2018). Rettig et al. (2020) developed the Female Empowerment Index (FEMI), which measures six domains of empowerment (Intimate Partner Violence, Access to Family Planning, Reproductive Healthcare, Employment, Education, and Decision-Making). This index was recently computed for first level sub-divisions of all countries in sub-Saharan Africa (SSA) (Rettig & Hijmans, 2021). This makes it possible to use FEMI to examine associations between empowerment and various ecological and economic factors within and across countries.

Here we use the FEMI to examine the association between FEMI scores for the most recent available year (2015) and six potential factors influencing its status: travel time to the nearest city, mean annual temperature, mean annual rainfall, geographic distance to the coast, GDP per capita, and population density. We examine trends at both the continental and country/regional levels.

Methods

Data preparation and analysis was conducted in the R programming language (R Core Team, 2021), using the "randomForest" (Liaw & Wiener, 2002) and "terra" (Hijmans, 2021b) packages. The FEMI scores for 2015 (Figure 3.1a) were taken as a first-administrative level response variable. We examined six predictor variables that had data available for 2015: travel time to the nearest city, mean annual temperature, mean annual rainfall, geographic distance to the coast, GDP per capita (adjusted for purchasing power parity), and population density. Each response variable was available for a 30 arc-second spatial resolution (approximately 1 km^2).

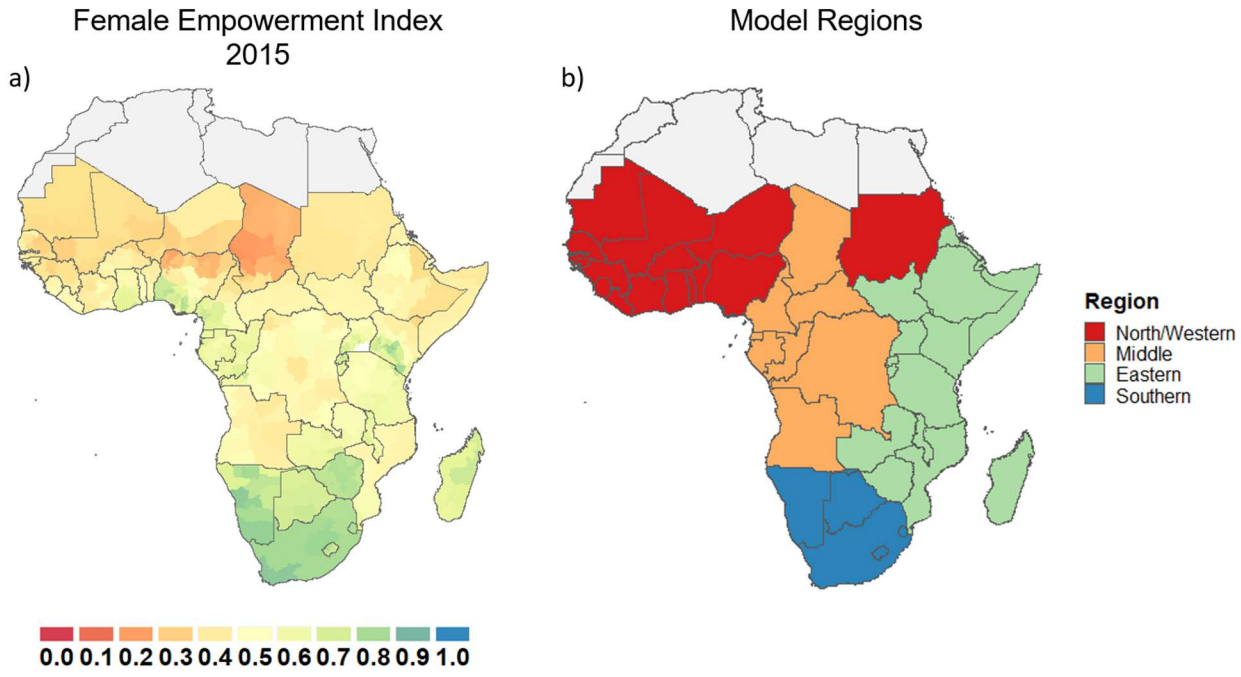

Figure 3.1: a) The Female Empowerment Index (FEMI) for sub-Saharan Africa for the year 2015, by first-level administrative subdivisions (Rettig and Hijmans, 2021). b) The regionalization used for modeling.

The following 30 arc-second resolution spatial data sets were obtained or derived from various sources that had coverage for all countries in sub-Saharan Africa for the year 2015. Geographic distance to the coast was calculated based on rasterized Global Administrative Areas data (Hijmans, 2021a).Other data used include rasterized mean annual rainfall and temperature (Fick & Hijmans, 2017), GDP per capita (Kummu et al., 2018), population density (Center for International Earth Science Information Network - CIESIN - Columbia University, 2018), and travel time to the nearest city (Weiss et al., 2018).

These data were used as predictor variables and they were aggregated from grid cells to compute the population weighted mean first-level administrative subdivision values to match the FEMI data. Population weighting was used to ensure that the overall values were reflective of the geographic location of populations within each first-level subdivision.

Travel time to the nearest city was available for three different thresholds: a minimum of 5,000, 20,000, and 50,000 people. To assess which of these was the most associated with empowerment, we compared empowerment versus each threshold using Pearson's correlation coefficient. The threshold of 5,000 people had the highest correlation and was chosen as a response variable. We confirmed these results using a random forest (RF) model containing index as a predictor variable and each of the three data versions, which also demonstrated that the 5,000-person threshold was the most closely associated with changes in empowerment.

To capture urbanization and its effects on empowerment, we assessed potential population density cutoffs for urbanized areas, with densities between 250 and 5000

people per square kilometer. All densities showed poorer correlation with empowerment ($R^2 < 0.10$) than the raw population density data, which had an R^2 value of 0.17. For this reason, we used population density directly rather than attempting to capture an urban area threshold.

The FEMI data was then normalized by subtracting all the median FEMI score for each country from all its values. These normalized values capture within country level variation, but not between country variation in the overall level of FEMI.

We grouped each country into one of the United Nations-defined regions for sub-Saharan Africa to create regional models.. Because the Northern region has only two countries situated within SSA (Mauritania and Sudan) we added these to West region to form the North/Western region.

Models comparing the predictor and response variables were then developed using the Random Forest algorithm. We assessed continental-level predictive quality using a model for all of sub-Saharan Africa for both raw and normalized scores, as well as examining predictive quality of normalized data for each country in sub-Saharan Africa.

Results

The continental model has a R^2 of 0.24 for the normalized FEMI scores and 0.66 for the non-normalized (hereafter referred to as “raw”) FEMI scores (Table 3.1).

Temperature was the most important predictor for the raw model, followed by rainfall and population density. Population density was the most important predictor for the

normalized model, followed by temperature and travel time to the nearest city of at least 5,000 people (Tables 3.1 and 3.2). The two environmental factors were much more predictive in the raw model, comprising the first two most important predictors (temperature at 75.5% increase in MSE and rainfall at 38.5% increase in MSE). In contrast, the normalized model only had temperature (20.1% increase in MSE) as one of the first four predictors.

The model fit of the raw regional models was also consistently higher than that of the normalized regional models, with an average R^2 of 0.55 for the raw models and 0.13 for the normalized models, so it appears that data normalization removes significant predictive ability.

Table 3.2: Performance of Random Forest models predicting FEMI scores at first level subdivisions in Sub Saharan Africa for the continental or four regions. Except for "Continent-raw", all models used normalized FEMI values. Statistics are out-of-bag estimates. Negative R^2 values signify that the model has worse performance compared to using the Null model of using the mean value for that region. The increase in Mean Squared Error (MSE) for a variable indicates the deterioration of model quality when randomizing the values for that variable. Thus, the higher the score, the more important the variable is for model quality.

Region	**R^2**	**Increase in Mean Squared Error**					
		Travel time	Temperature	Rainfall	Distance to Coast	GDP per capita (PPP)	Population Density
Continent-raw	0.66	26.8	75.5	38.5	31.1	27.6	32.5
Continent	0.24	19.6	20.1	11.6	19.9	15.3	36.9
Middle	0.00	7.0	4.5	1.3	7.3	7.8	12.9
Eastern	0.21	14.8	6.9	12.3	13.9	12.8	28.7
North/Western	0.36	7.8	9.9	8.8	21.4	11.0	19.9
Southern	-0.05	6.9	-1.2	0.9	5.7	7.6	3.4

There were large differences in the quality of the regional models. Although the overall Random Forest R^2 values for the raw models were all positive, the R^2 values for the normalized FEMI scores had a very large range. The North/Western regional model had the highest predictive value of all normalized models, and the Eastern regional model also had positive predictive value. However, the Middle and Southern regional models had R^2 near zero, indicating that these models had no predictive ability (Table 3.2).

Population density was the most important predictor for the Eastern region, as for the continent, and was the second most important predictor for the North/Western region. Distance to coast was the second most important predictor overall of women's empowerment. It was most important predictor for the Western region and third most important for the other two models. Rainfall was not among the first four predictors for any of the normalized models (Table 3.3).

Table 3.3: The first through fourth most important variables for normalized Random Forest models. The Middle and Southern regions are not included because their R^2 value were less than or equal to zero, indicating no predictive quality.

Region	**Variable Importance**			
	First	Second	Third	Fourth
Continent	Population density	Temperature	Distance to coast	Distance to nearest city
Eastern	Population density	Distance to nearest city	Distance to coast	GDP per Capita (PPP)
North/Western	Distance to coast	Population density	GDP per Capita (PPP)	Temperature

It is also importance to consider the quality of each predictor. Population density has a much higher score than other predictors for the continental and Eastern models, while

the importance of population density is just short of distance to coast for the North/Western (20.0% versus 21.4% increase in MSE, respectively; Figure 3.2). Temperature, travel time to nearest city, and distance to coast had clustered importance with very similar predictive values for the continental model (around 20% increase in MSE). Distance to the nearest city of at least 5,000 people was relatively important for the continental and Eastern Models but had the lowest predictive value for the Western model.

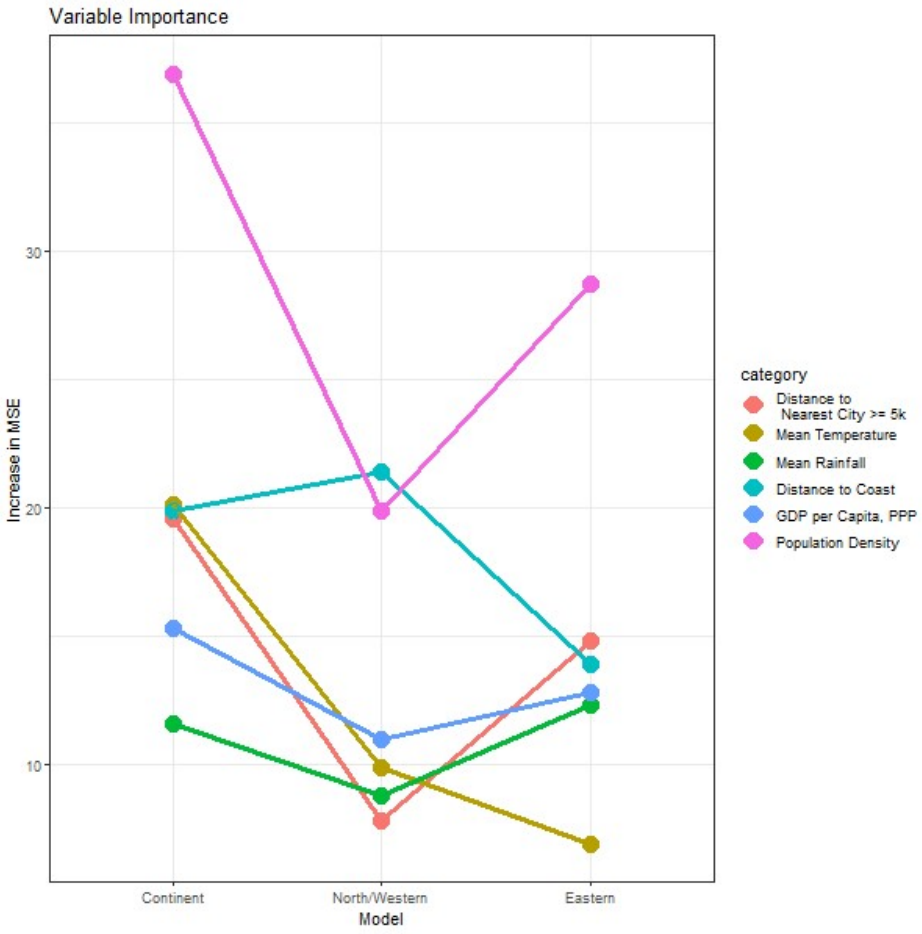

Figure 3.2: Variable Importance for each predictor, represented by increase in percent Mean Squared Error for out-of-bag estimates for each Random Forest model. The Middle and Southern regions are not included because their R^2 value was below zero, indicating no predictive quality.

Partial dependence plots are an additional way of examining how the predictors affect the FEMI score (Liaw & Wiener, 2002), and are particularly useful for “black-box” algorithms such as Random Forest. For population density, the plots are similar for all three models, rising sharply as population density increases at low levels, then leveling off around 1000-2500 people per sq. km, depending on the specific model (Figure 3.3).

The other partial importance plots have varying results. For the North/Western region, the distance to coast graph drops off rapidly until around 5000 km, where it levels out. Living within around 100 km of a coastline shows a positive effect on empowerment, while distances beyond that show a negative effect, although the pattern is slightly irregular, possibly due to lack of data at certain thresholds. Temperature in the continental model and distance to the nearest city in the eastern region behave more unusually. Temperature follows a slight linear decline until around 18°C, then has a steeper linear decline, but there is a sharp outlier drop at around 26°C. Distance to the nearest city in the eastern region appears not to follow any clear pattern, and this graph may indicate that Random Forest is picking up on a spurious correlation.

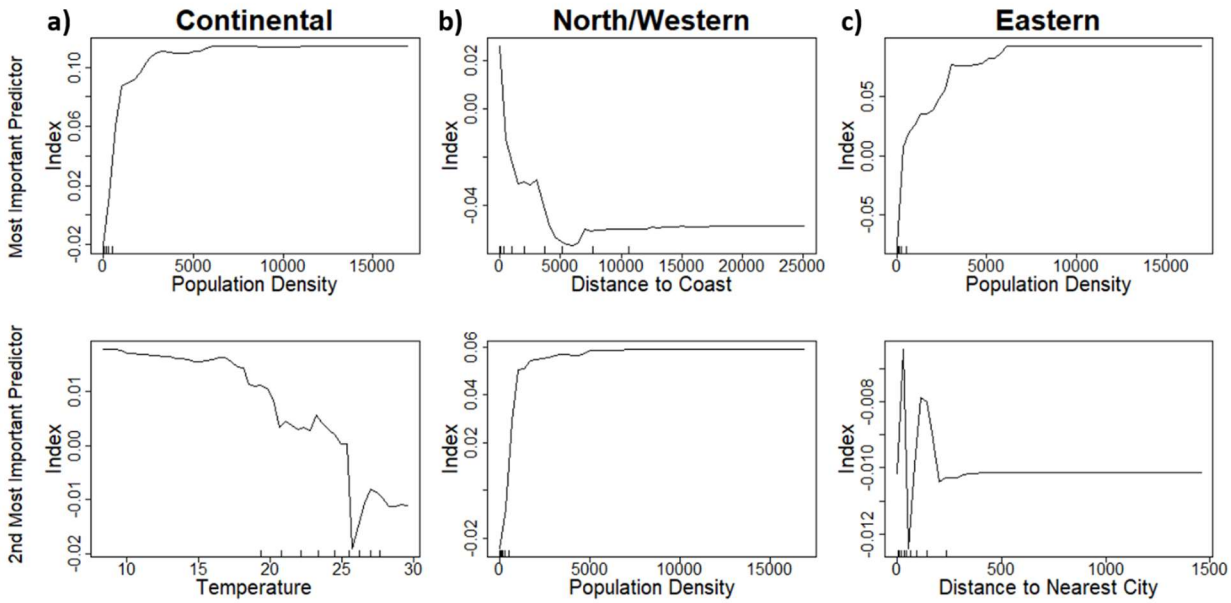

Figure 3.3: Random Forest partial importance for the most important predictors (top row) and second most important predictors (second row), for the a) Continental, b) North/Western, and c) Eastern models for first-level subdivisions of countries in SSA.

When including country-level effects in the continental model, their effect is substantial. The overall Random Forest R^2 for the continent increases by 0.13, and including country increases the R^2 by 0.10 for the North/Western region and 0.07 for the Eastern region. It becomes the second most important predictor for the continent, behind population density. While most countries have a partial dependence of around +/- 0.02, Cameroon, Kenya, and Nigeria are outliers, with a partial dependence of -0.05 or less.

Discussion

We have examined the connection between six predictors and the Female Empowerment Index at both the continental and regional levels. Population density was the most important predictor across the three models retained. This is perhaps not surprising as people in cities tend to be wealthier, and cities provide higher quality

access to education and more health services, and higher average wealth lets more women utilize these services.

The strong response to empowerment seen in the partial dependence plots at low population densities is somewhat surprising because a majority of data lies at densities well below what is generally considered an urban area. It appears that even small changes in the density of a location may have large effects on the empowerment of women. This may provide a challenge to designing interventions to improve empowerment in the least empowered areas, as providing services in low-population density areas is likely to be rather inefficient in terms of increase of empowerment per dollar spent. However, there are potentially large gains to be made even in locations with moderate population density such as small towns and their adjacent rural areas. It may be most beneficial to target interventions (e.g. better schooling and medical facilities) in that type of location.

Distance to the coast was also one of the most important factors amongst the three models. Prior research identified that proximity to paved roads was a significant predictor of women's empowerment (Sell & Minot, 2018), and these are more likely to occur in urban areas. Urban areas themselves tend to cluster along coastlines rather than in the interior of a country, giving another possible explanation for its high predictive value.

The high partial dependence of country within the continental model suggests that the model is not accurately capturing countries with significant internal variation. Cameroon, Nigeria, and Kenya all have substantial subnational variation within their FEMI scores at the first-level administrative subdivisions. These countries also show as outliers within

the partial dependence plot for country. Countries that are more uniform subnationally, such as Congo, show a lower importance of country within the continental model. It is possible that the continental model is failing to differentiate these more unusual first-level administrative subdivisions within these countries in favor of the more uniform results of most of the continent.

Conclusions

We found that population density is a key predictor of women's empowerment, even at very low densities. Our results can be a starting point for additional research into the broad factors underlying women's empowerment. Future work could investigate which empowerment domains of the FEMI are most strongly correlated with population density and other variables. Women's empowerment is an important concept for women, men, children, and entire communities. The focus on "urban" versus "rural" areas misses the tremendous amount of diversity and there is an opportunity for interventions to improve women's empowerment in lower population density areas.

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