AGRICULTURAL LEADERSHIP, FAMILY-PLANNING COMMUNICATIONS, AND EDUCATION: GHANA, LIBERIA, AND SENEGAL IN WEST AFRICA

A Dissertation

by

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ABSTRACT

This dissertation embraces three topics for Ghana, Liberia, and Senegal: agricultural production and household food security, family planning communications, and empowering rural women.

From 2012-2013 field survey data representing agroclimatic and farming conditions, our Chi-Square Automatic Interaction Detection identified community support and gender-based farming practice as the most significant predictors of Liberian and Senegalese food insecurity. In Liberia, almost all severely food-insecure households had no village-wide food support in the worst food-insecure (rainy) season. More decision criteria, including crop selling locations, natural irrigation amid inadequate farming technologies, agricultural information, off-farm income, land conflict, and informal labor, followed. In Senegal, female-headed households produced less food than male-headed households, so was the amount of *Zakat* (involuntary almsgiving) and *Sadaqah* (donation). For Ghanaians, the random forest algorithm identified crop income and farming inputs as more important predictors than exogenous assistance, gender-based farming practice, and land conflict.

Despite more outside farmworkers, technologies, and investment in Ghana than Liberia or Senegal, rural youth often leave their villages. Ironically, sub-Saharan Africa will only grow the population steadily in this century caused by unmet needs among teenagers.

We applied two seemingly unrelated methods— Instrumental Variable (IV) estimations and Coarsened Exact Matching (CEM)-weighted multiple regressions for aggregated information of Senegal Demographic and Health Surveys (DHS). The result was consistent that to 15-to 49-year-old women who were married, living with partners, fecund, and pregnant, radio

communications in family planning and contraception independently reduced the optimal number of children desired. Joint decisions of female and male partners, or wives and husbands, on family planning are essential.

We then found from multiple years of DHS the effects of wives' and husbands' education, literacy, and interaction of age and urban residence on positive household wealth. Our ordinal categorical regressions also found evidence that more children five years or below, higher intimate partner violence (IPV) tended to lower wealth. Average marginal effects implied more exposure of rural women to IPV, and they had fewer educational opportunities than their urban sisters. Our study suggests that the mutual support of husbands and wives for equal education is of paramount importance.

DEDICATION

To my family, who supports, believes, and is patient with me.

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I thank my dissertation committee, Dr. Gary Briers, Dr. Manuel Piña, Dr. Robert Strong and Dr. Edwin Price. I could have never presented the dissertation without guidance and advice. Through not research discussions, development, and publications, but classes and conferences with the committee, I could find my research path in the forest.

Days or evenings, and weekdays or weekends – Dr. Briers responded to my questions, inquiries, and requests to move research forward. Not as a major academic advisor but a mentor, Dr. Briers helped my doctoral life have never been better.

For the first time in the Department of Agricultural Leadership, Education and Communications, Dr. Piña allowed me to expand the scale and scope of research from five conferences.

Like almost all doctoral students, I had several up-and-downs. Whenever I was discouraged, Dr. Strong raised me returning to the study. Also, the course of Instrumentation and Survey Research Methods brings the importance of survey-based research.

I could not imagine my time at Texas A&M University without the Center on Conflict and Development (Center). Since my Master’s in Agribusiness, Dr. Price visited South Korea and Ghana several times to keep my focus, career, and passion in international agriculture development. Not every piece of field interviews, information, and observations, but other hands-on experience helps me find research questions, apply methods and justify implications.

Finally, three more people I should thank. The Center’s Associate Director, Dr. Shahriar Kibriya, has provided numerous teaching and research opportunities. The Coastal Plain Soil, Water and Plant Conservation Researcher in the United States Department of Agriculture’s

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We only think when we are confronted with problems. – John Dewey

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by the dissertation committee, Professors Gary Briers [advisor], Manuel Piña and Robert Strong of the Department of Agricultural Leadership, Education and Communications and Professor Edwin Price of the Department of Agricultural Economics.

All work for the dissertation was completed independently by the student, under the advisement of Professor Briers of the Department of Agricultural Leadership, Education and Communications and Professor Price of the Department of Agricultural Economics.

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NOMENCLATURE

CEM	Coarsened Exact Matching
CHAID	Chi-square Automatic Interaction Detection
CONDEV	Center on Conflict and Development at Texas A&M University
DHS	Demographic and Health Surveys
DTA	Decision Tree Algorithms
HGBF	Howard G. Buffett Foundation
ICSC	International Civil Service Commission
ICT	Information and Communications Technology
IPV	Intimate Partner Violence
IV	Instrumental Variable
LISGIS	Liberia Institute of Statistics and Geo-Information Services
RFC	Random Forest Classifier
SSA	Sub-Saharan Africa
2SLS	Two-Stage Least Squares
USAID	United States Agency for International Development
USD	United States Dollars

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CHAPTER I

INTRODUCTION

The world faces a challenge: a viable food supply to meet the demand of 7.8 billion people today and 9.9 billion by 2050. Kaneda et al. (2020) further predicted sub-Saharan Africa (SSA) would be a primary driver of the population growth and will need 60% more food in three decades based on the year 2005/2007 (Van Ittersum et al., 2016). However, the supply-and-demand equilibrium seems distant. Godfray et al. (2010) reasoned insufficient farm inputs, technologies, and techniques but increasing competition for essential natural resources of energy, land, and water in climate change. The described factors make today's staple crop productivity stagnant from the 1960s.

Ghana, Liberia, and Senegal are a mirror of SSA. Ghana's, Senegal's, and Liberia's populations are high and medium among 58 African countries in the 13th, 23rd, and 37th places, respectively (Worldometer, 2020). The rural population reversed the tendency (Figure 1.1, World Bank, 2018a). Cereal yields looked stagnant or a little progress. Meanwhile, world yields nearly tripled to 1,432 Kilograms (kg) per Hectare (ha) to 4,074 kg/ha between 1961 and 2017. While Liberia and Senegal showed slower progress, i.e., 550 kg/ha to 1,275 kg/ha, Ghana only followed the steady, upward trend after the world, i.e., 816 kg/ha to 1,873 kg/ha (Figure 1.2, World Bank, 2017b). Correlatively, the amount of fertilizer consumption and tractors in the field of the world's average differed significantly from these three countries in SSA (Figures 1.3 and 1.4, World Bank, 2017c, 2017d). Rural Ghana, Liberia, and Senegal continue to lose attention and competitiveness, reducing agriculture's contribution to the total Gross Domestic Product (Figure 1.5, World Bank, 2018e).

Figure 1.1 Rural Population (% of total population) - Ghana, Liberia, Senegal, World

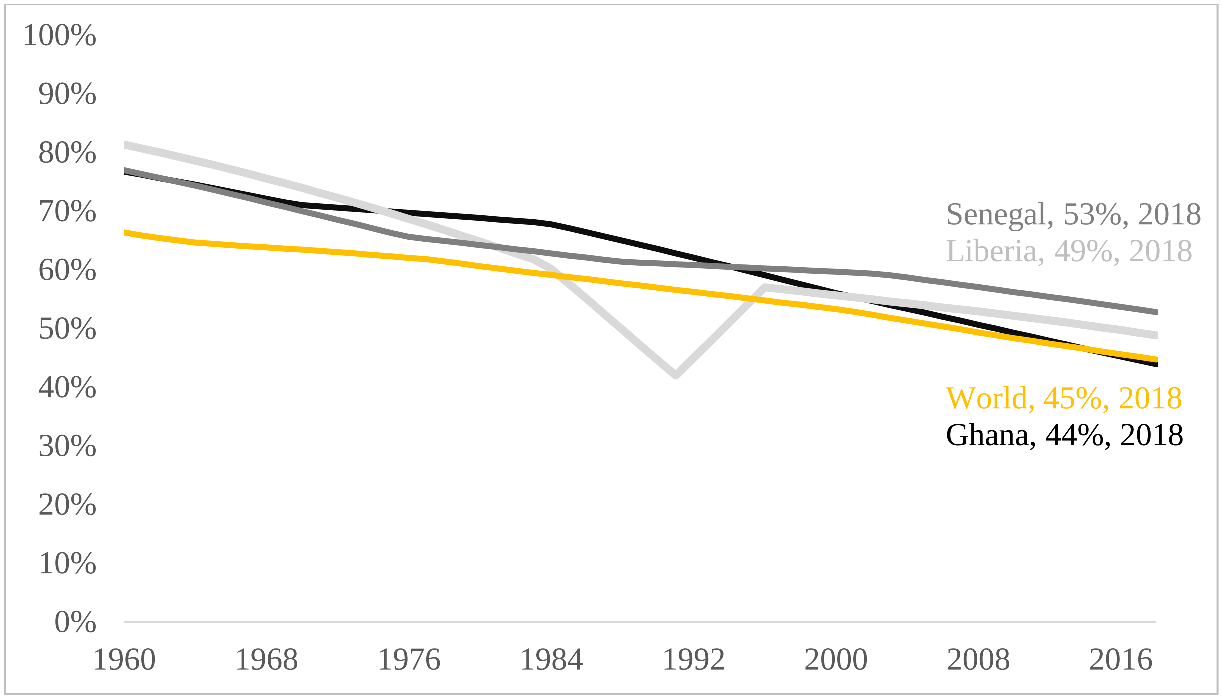


Figure 1.2 Cereal Yield (kg per hectare) - Ghana, Liberia, Senegal, World

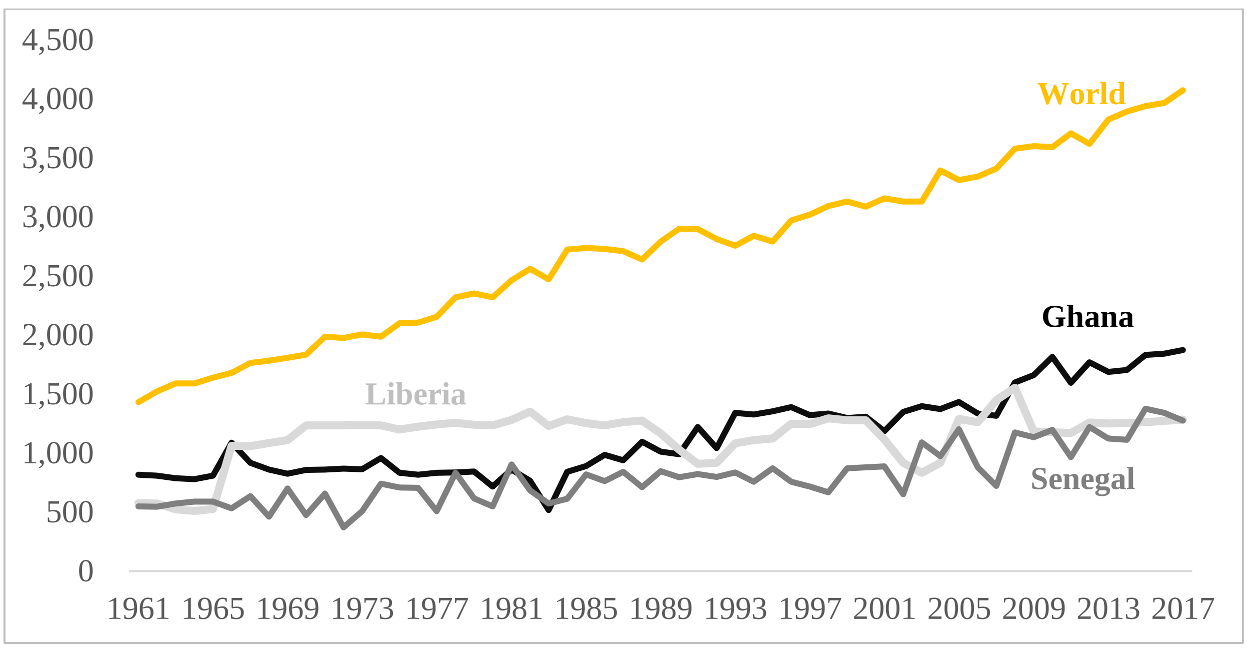


Figure 1.3 Fertilizer Consumption- Ghana, Senegal, World

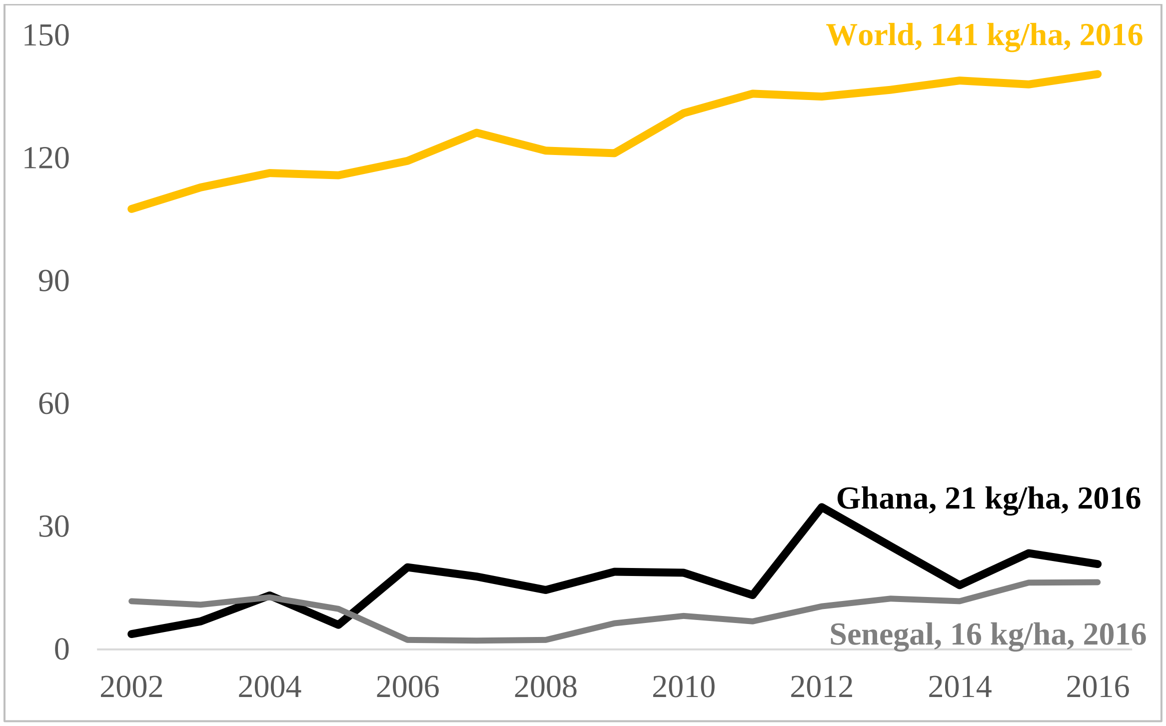


Figure 1.4 Tractors per 100 km^2 of Arable Land

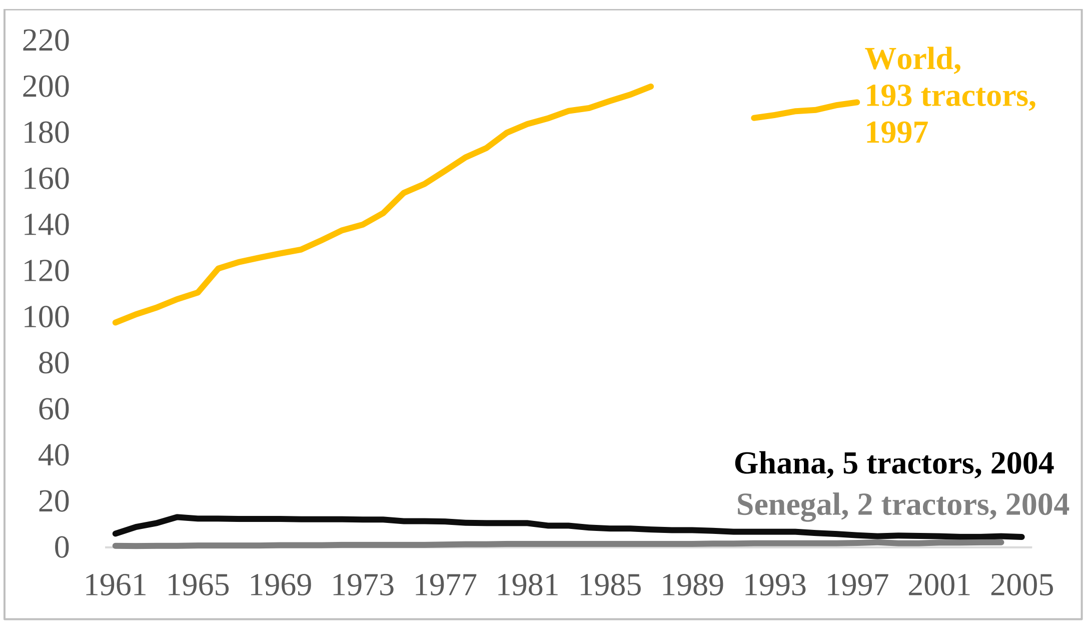
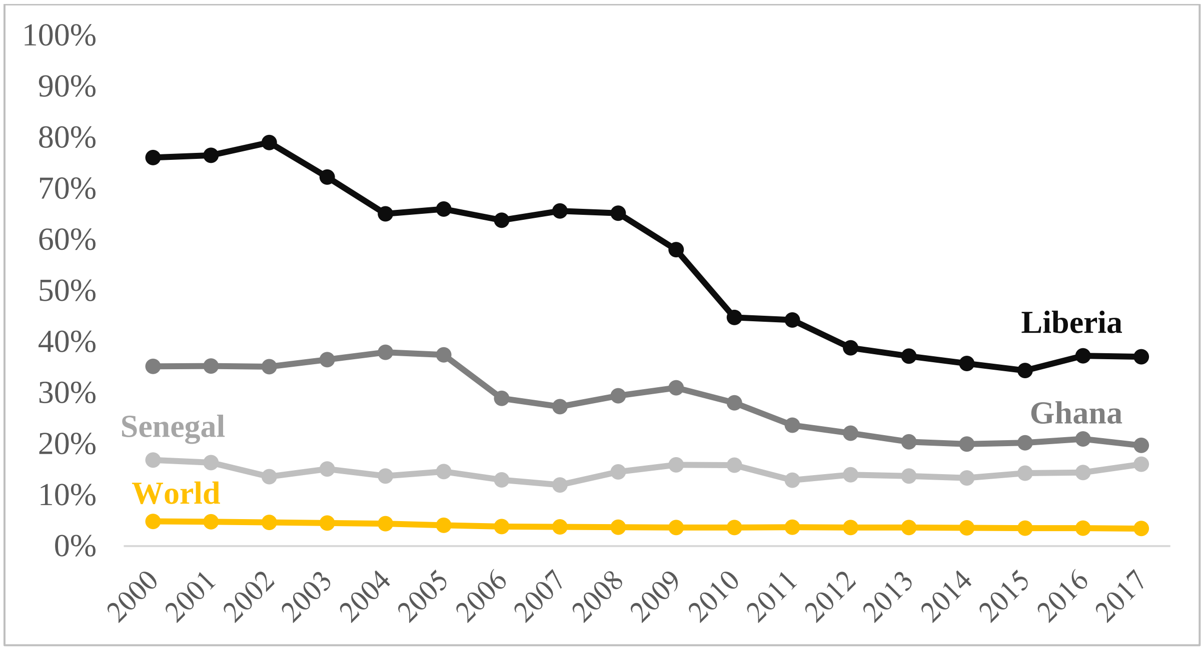


Figure 1.5 Agriculture (% of GDP) - Ghana, Liberia, Senegal, World



Here serious concern would be food insecurity among smallholder and subsistence farmers. Flores (2004) traced the proportional change of malnourishment in West Africa between 1980 and 2000. Ghana made the most significant progress or reduction, followed by Nigeria. In contrast, Senegal and Liberia failed to reduce much of their malnourishment. Among the nine comparison countries, Ghana was on top, nearly middle for Senegal, and the lowest for Liberia. The tendency continued to 2017 when only 6% of Ghanaians experienced prevalent malnourishment, while 11% of Senegal (close to the world's average, 10.8%) and Liberia marked 37% (World Bank, 2018f). In Chapter II, we searched for factors causing food insecurity and security in agricultural leadership.

Then our focus moved from why to how to pursue a balanced growth between villages and major populous cities. To propose, Ghana's final random-forest model branched off the node of food security and food production levels and ended the family labor node (size of three). Family labor as human capital is imperative to sustain rural communities in furnishing man/woman power for agricultural production and making decisions of each household, neighborhood, and village. The irony is that rural youth from an extended family leaves for Accra and Kumasi, two capitals of Ghana. Once settled, neither do they return to home nor extend family. An Accra resident responded, *who affords extended families*? (Maritz & Probyn, 2017). We proposed family planning for this irony.

Family planning does not mean giving fewer births. Family planning helps couples decide a realistic and ideal family size exposed to situations, environments, conditions, and other considerations. Every woman must have the right to give birth free from sexual assaults and intimate partner violence—today's rising concerns about sexual violence in Liberia rings the alarm for this fundamental right amongst women (Doyal & Gough, 1991; Al Jazeera, 2020). In Chapter III, we found causal evidence that exogenous factors (treatment) of radio communications on family planning, together with contraceptive use, helped reduce the family size by the nearly ideal number of children (the current and expected number). The real value was not a reduction. Instead, the study highlights a need to balance the minimum of zero to a maximum of 30 children. As one example, a couple wanted another if they lost a child.

Maritz and Probyn (2017) reported a common trend of 10 African megacities that the middle-class, whose income equals or is more than $4 daily, pursue higher education for success. With the same Demographic and Health Survey datasets, which recorded females 15 to 49 years of age, we tested in Chapter IV how education consistently increased household wealth. As a result, a woman’s schooling and her partner's schooling were proportionate to their wealth. Similarly, the frequency of reading magazines or newspapers as an indirect measure of literacy was positively related to wealth. On the other hand, larger numbers of children to care for and higher intimate partner violence cases reduced wealth.

CHAPTER II

FOOD PRODUCTION AND HOUSEHOLD FOOD SECURITY

2.1 Introduction

The meaning of food security is evolving and becoming complicated as new challenges emerge. Recent diseases test constant food supply and demand. Hatlebakk (2020) summarized 20 relevant studies indicating that the inability of labor mobilization or fear of infection of contagious disease lowered agricultural productivity. Market closure was also a detriment for farming households to gain adequate nutrition from market items.

Given consideration of disease-free or back-to-normal circumstances, still, persistent challenges remain. More cases of drought, floods and pests, lack of farming technologies and techniques, and social norms or conflicts call for the comprehensive and comparable context of food security (Barrett, 2020).

Ghana, Liberia, and Senegal in West Africa experience the factors above. Also, agricultural production from smallholder and subsistence farmers is stagnant, with a diversity of economic sectors, a decrease in rural population, and less employment in agriculture. Bill Gates (2020) accentuated a chain of concerns. Sub-Saharan Africa will need more food as the population expands more than double to 2.5 billion, that is, twice that of Europe and North America combined by the forecasted year of 2050. And population growth will cause enduring malnutrition.

2.2 Objective and Research Questions

This study was to understand food security holistically and empirically. Sufficient quantitative and pertinent qualitative information contributed to the development of research questions:

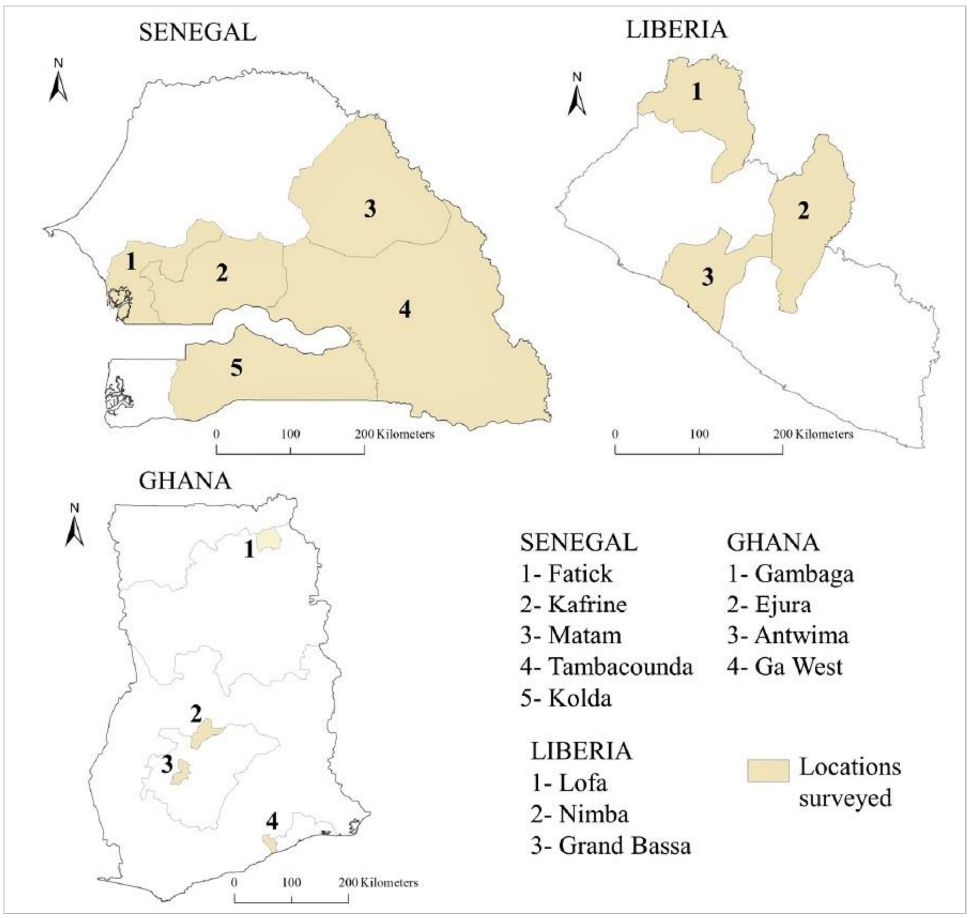
1. How could survey-based information apply to food-security dimensions?
2. Which agricultural predictors made food security similar and different in rural Ghana, Liberia, and Senegal?
3. Accepted national, regional, communal, and gender-headed household differences, how was food security further explained?
4. In the realm of social science, what were considerations for future food-security study?
5. All results combined, what were the implications for agricultural leadership?

2.3 Survey Area

Supported by the Howard G. Buffett Foundation and teamed up with local government officials, the Center on Conflict and Development at Texas A&M University field-surveyed four districts of Ghana, three counties of Liberia, and five Senegal regions from October 2012 to April 2013 (Figure 2.1) (Note the figure is from Sohoulande Djebou et al. (2017) that I was a co-author and involved in the overall assessment.). Overall, 647 Ghanaian, 326 Liberian, and 510 Senegalese households, those who voluntarily and randomly participated, allowed 30-50 minutes to respond to over 160 questions in 16 sections (For Liberia survey, additional eight questions in a separate section were to learn the impact of the 14-year civil war between 1989 and 2003 on the interviewees and their families.).

Not only interstate but also inter-regional variations helped viable study. Selection of diverse ecological zones for various farming practices, each country's breadbasket, and farming households' concentration and spatial advantages to off-farm and market activities enlightened us to compare one district/county/region to another within a country.

Figure 2.1 Study Locations



Note. Reprinted from Sohoulande Djebou, Price, Kibriya, and Ahn (2017), whose publisher permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

2.4 Precedent Study Findings and Categorization of Food Insecurity/Security

The earlier findings suggested more concrete methods and results for the completion of the study. Sohoulande Djebou et al. (2017) discovered a causality of farm assets and food security for Ghana and Senegal. Later Ahn et al. (2020) magnified 112 female-headed Liberian households for factors causing food insecurity. The former left a possibility for inter-regional comparisons; the latter gave more insight into contextual Liberian agriculture and gender-headed household comparisons.

A new chapter study employed expanded and improved decision tree methods to classify 1,476 farming households. (Four Ghanaian- and three Liberian interviewees excluded for analysis due to no farming-related activities or no data for critical variables.)

As a data-mining tool, decision trees have advantages. The models primarily accommodate relatively large datasets to select and determine predictors' relative significance to explaining the target variable. The models also accommodate the skewness of continuous predictors, outliers, and one-sided observations of categorical variables. Tree-shaped results help provide easy-to-read results and lead to straightforward interpretations. All-in-one from empirical data, explanations of the tree models make food security and reasons for food insecurity possible (Song & Ying, 2015). A wide range of financial and non-financial predictors enlighten to make various decisions on advertising a new product to target customers or the effectiveness of treatment on a disease in a clinic or hospital.

We applied separate trees for classifying food-security households. Persistent food insecurity is a concern of Liberia and Senegal. Practically 78 percent of Liberian and 74% of Senegalese families lacked food for longer than two months. Contrastingly, more (63 percent) experienced no, unequal, or shorter than a month of food shortage in Ghana.

Malnutrition and food shortage—both described different food-security statuses of the three countries. And according to the Food and Agriculture Organization of the United Nations (FAO, 2006), socioeconomic resources to access more nutrient food items were equally crucial for a measure of food security. Table 2.1 displays how food (in)security was constructed.

Table 2.1 Food Security Construction Criteria

Dimension	Understanding	Question
Stability	Days and months of food shortage	1. (Yes/No) During the last 12 months, has your household experienced out of food? 2. (Less than a month/One month/Two months/Three months/For months or longer) If yes, how long would lack food?
Food availability	Days of quality food	1. (Days) During the last 12 months, has your household relied on less quality, less preferred, or less variety of food? If yes, how many days last?
Food access	Resources to acquire food items for a healthy diet	1. How many days (over the past seven days) has your household eaten these food items? (<u>Carbohydrate</u>) Maize, Wheat flour, Millet, Rice, Cassava, Other roots/tubers, Plantain (<u>Protein</u>) Red meat, Fish/seafood, Poultry, Wild and bushmeat, Milk/dairy, Eggs (<u>Fat</u>) Oil, butter, shea, Pulses, beans, nuts (<u>Vitamins</u>) Fruits (<u>Sodium</u>) Condiments 2. Does each consumption represent (more/less/about the same) compared to days answered?

Actual questions represent each dimension. Categorization based on all the responses was straightforward. Only those who experienced equal or less than a month of food shortage, less quality/preferred/variety of food, earned the designation of mild food insecurity. Cases in this category had at least one to two food items per nutrient about the same or more consumption. Lower-tier, moderate food insecurity accommodated others who had two to three months of food instability (often around rainy seasons) and days of less quality/preferred/variety of food. Food access played a critical role in differentiating between moderate food insecurity and severe food insecurity (Maxwell et al., 1999). Although stability and food availability satisfy the moderate condition, inadequate nutrition daily, a minimum of two missing of four nutrients, resulted in designation as severe food insecurity. In neither case did condiments count as a significant nutrient. Insufficient food for four months or longer made household food insecurity severe.

On reflection of food availability and access, Ghanaians of no, equal to, or shorter than a month of food shortage resulted in a reduction from 63 to 57 percent or 408 to 367 households of mild food insecurity. Under the more stringent criteria and about equal proportion, only 57 percent was in food secure. While Ghana's classification was dichotomous, whether food secure (=367) or not (=277), Senegal nationwide held more moderate food-insecure families (45 percent or 230 of 510 families). In Liberia, more households (129 of 323) faced severe food insecurity than others with moderate (=112) or mild (=82) food insecurity.

Two separate questions about sometimes to frequent food supply purchased on credit or provided by neighbors were part of community support in a broader sense. The support covered village-wide food aid, farmer training, and occasional village-council loan extensively. To several villages, neighbors bartered, shared, or bought their produce also marked community support.

Communal resemblance appeared in producing crops, saving harvest to cope with food insecurity, finding buyers, and transporting produce. In geography, advantages gave additional exogenous assistance from the government, a farmer's organization, or non-governmental organizations (NGOs). Near a town or city market, community members could supply and simultaneously demand extra food easier than others residing farther away.

2.5 National-level Summary Statistics

A wide range and various survey questions and responses benefited quantitative information as binary, continuous, or count variables, with some nominal and ordinal categories. Financial information was equally crucial to non-financial data.

Currency conversion was essential to compare all-in-one, all at once. Every Ghanaian Cedi, Liberian Dollar, and West African CFA Franc for Senegalese Currency equalized at the rate of 0.5248, 0.01361, and 0.00198 US dollar (USD) the midpoint of the survey in order (International Civil Service Commission (ICSC), December 2012). Conversely, one USD equals 1.9 Cedis, 73.5 Liberian Dollars, and 505.1 Francs.

Two significant financial information pieces are worth noting. First, every Ghanaian and Senegalese household income was divided into the crop, off-farm, and animal income. Liberia is in post-conflict, and both literature and field observations reported early and insufficient time for livestock domestication (Murphy et al., 2016). Second, all ex-post information combined, average household income followed GDP per head in 2012 and 2013 (constant 2010 USD) for Ghana, 1542.69 and 1617.47; for Liberia, 564.52 and 597.38; for Senegal, 1290.36 and 1290.16 all in USD (World Bank, 2018g). Mean household income for analysis was 1736.05, 553.23, and 1323.23 for the three countries, in the same order as above. The amounts for Ghana and Senegal and HGBF (2013) looked almost identical. But there was a difference of 373 USD in Liberia because new estimates took more cost information into account.

The gap arose after various cost items for the same agricultural practices, outside labor, transportation, and selling channels were standardized and reflected against revenue village-to-village. Instead of relying on individual responses and records, an extensive search of the most informative cost information helped us get coherent cost-adjusted crop income for all three countries and animal income for Ghana and Senegal. However, no exact cost information was available of any tax-incurred or other-incurred cost functions. The surveyors asked if additional household members contributed to the amount of income with jobs. They mostly matched village wide.

Before looking closely at regional similarities and differences, country-to-country comparisons helped see a larger picture (Tables 2.2, 2.3, and 2.4). Proportionally, average crop income took approximately 73% of Ghanaian-, 78% of Liberian-, and 71% of Senegalese average household income. In Ghana, off-farm income (20%) and animal income (7%) enhanced the income, compared to about equal contributions of off-farm income (15%) and animal income (15%) for Senegalese households. For Liberian families, 22% off-farm income was added to the 78% crop income.

Credit could support farming activities. For instance, amid lacking formal financial institutions, Liberia employed informal savings clubs, known as "*susu clubs*," operating as a quasi-bank to lend the principal, conditioned interest rates, and various payment terms (Cruz, 2014; Tarway-Twalla, 2011). Despite the usefulness of *susu clubs*, credit users who were not club members bore higher interest rates (often 50% of/to the principal) and more stringent repayment requirements (mostly circulated in three months). This induced Liberian households to rely less on credit and more on their income and other lenient sources for a farm- and additional household investment. Ahn et al. (2020) observed the tendency to 33 entrepreneurial female-headed families of 112 cohorts. Inclusive of 323 of both genders who are heads, median and mean credit was 27.58 USD and 64.70 USD, with a maximum loan of 965.30 USD.

Schindler (2010) reported in Tamale, Northern Ghana, that wholesalers, '*susu*' groups and traders played independent informal microcredit providers to market women while banks hesitated to take over little collateral responsibility for a loan. Rural households covered insufficient funds for farming and family expenditures through the listed informal channels and formal ones, including the village council, government, and NGOs.

Like Liberia, the role of credit in Ghana remained positive and negative. Arku and Arku (2009) and Ganle et al. (2015) conditioned factors of a household member who culturally controls credit (either husbands or wives), acknowledges the amount indebted, and can repay due course are determinants between positive-and-negative extremes. Market women and farmers have a comprehensive relationship as small informal creditors and borrowers, a go-between producer and merchant, a quasi-trader, and villagers in outlying areas from major cities as agriculture-related informants to farmers. With those characteristics, the median and mean credit were 32.51 USD and 9.39 USD higher than Liberia.

For Senegal, no compelling informal microfinance agents appeared among those surveyed. Thus, credit sources were limited to neighbors, relatives, village councils, or governments to those who were public servants. The number of borrowers was lower than in Liberia and Ghana (= 0 USD as the median), but the mean was almost twice as large (=138.55 USD). Credit in Senegal hardly seemed a creditor-and-debtor relationship.

Unlike the other two countries, Ghanaian households provided separate and supplementary financial information. One was farm inputs. Sohoulande Djebou et al. (2017) corroborated agricultural technology-enhanced crop productivity and further food security of smallholder and subsistence farming households. We traced the USD amount spent on fertilizer and herbicide/insecticide. Despite our preference for the amount applied in place of financial information, several reasons remained so that respondents were reluctant to share. First, questions of payment for those inputs came in advance of the amount used for land.

Additionally, not a small number of farmers employed not only inorganic fertilizer that comprises nitrogen-phosphorus-potassium (N-P-K), urea, and ammonia but also organic fertilizer derived from animal waste (manure) and other farming debris (compost). Unexpectedly, the field surveyors learned that organic fertilizer involved financial transactions. Also, to obtain fertilizer and herbicide/insecticide, some farmers utilized their own money and government vouchers. Transacted costs occurred more in spraying herbicides or pesticides. Trying to standardize the amount used based on total payment was challenging. Among all reasons contemplated, one straightforward method was the completeness of payment responses in place of the exact amount applied to the field. The dimension of the farmer's knowledge of natural or chemical substances possibly made crop productivity different. For instance, in Ejura-Sekyedumase, farmers in the survey knew N-P-K's formulation for applications either 23-10-05, 15-15-15, or 23-10-10, herbicide, and pesticide likewise. In development, the introduction of herbicide by the time of the visit transformed agriculture in East Mamprusi of the Northern region. Based on differences, fertilizer and herbicide/insecticide acted as independent predictors for decision-tree analysis with moderate correlation, $\gamma = 0.43$.

All 644 households in four districts examined the minimum, median, mean, and maximum amount spent on fertilizer, zero, 96.03, 173.58, and 1842.04, all in USD. Comparatively, the median and mean paid for herbicide/insecticide was lower than for fertilizer (Median=36.74 and Mean=79.12), but a higher outlier amount (=2545.26 USD).

The questionnaire carried other financial information in Ghana. We assumed the amount spent on food was directly related to the level of food security. Despite the minimum amount of zero USD, the mean (=115.22) and median (=119.39) looked almost identical. The maximum USD amount was 367.36 in Ga West.

A similar question asked a portion (in percent) of the family to get extra food from the market for the last 12 months. Between the two, information on the latter question was not in analysis to the following. First, contextually, percentage questions assumed less accuracy than the money spent on food. Moreover, recalling a year (reliance on remembering from a more extended period) could cause a bias (Dillman et al., 2014). Over and above, difficulties of the question left many response lines empty.

Despite the questionnaire's invariable structure, neither information was adequate on food expenditure nor the proportion of family food from the market gathered for Liberia and Senegal. In Senegal, instead, the surveyors recorded critical Islamic *Zakat* and *Sadaqah* responses. Whether compulsory offering or not, *Zakat* discerns from *Sadaqah* or *Sadaqa*.

Sadaqah encourages Muslims or non-Muslims for spontaneous charity and donation, with no limit of time or locations. *Zakat* is of, by, and for the Muslim communities that impose a fraction on earnings for almsgiving. Like the Christian tithe, the Islamic *Zakat* expects believers to offer eight to 10% of proceeds or the same proportion of staple crops harvested. In *Zakat*, no exemption is, so practically a smallholder farmer whose crop fails due to a drought or flood hands over his/her obligation to another with no such disruptions. The 'wealth' or 'output' redistribution is meaningful not to share and help one another and further mitigate community-level food insecurity, but possibly estimate the amount of harvest (Taal, 1989). Shipton (1990) added the importance of *Zakat* and *Sadaqah*, where both stabilize community leadership, reduce government responsibility, and prevent a riot triggered by hunger. The study summarizes the amount of *Zakat* in kilograms of the minimum zero, median 140, mean 167, and a maximum of 850. Nationwide, the median and mean were similar.

Between continuous and count variables, the second to fourth tables cover binary predictor information. The common factors included gender and selling channels (or location). For female-headed households out of the total per nation, the Liberia survey team surveyed more (=35%) than Ghanaians (=26%) and Senegalese (=22%). But the number of counted Ghanaian females (=169) outnumbered Senegalese (=114) and Liberians (=112). By operational definition, female-headed households represented Ghanaian female farmers who actively managed farms, Liberian widow farmers sustained families, and Senegalese women growers led other wives and closely cooperated with them for agricultural production.

A surprise involved selling channels of the three countries. In ex-ante predictions, more Senegalese brought farm produce and livestock to a market than do Liberians. Ex post, however, the expectation became flipped such that more Liberians (=52%) sold crops outside the village than did Senegalese farmers (=21%). Consistent with ex-ante and ex-post, over half (=58%) of Ghanaian farmers used diverse selling channels at the market and major cities besides the village and middlemen (often market women and traders).

Assistance to subsistence-level farming households was imperative and dissected types. About 55% of Ghanaian farmers received at least a support of training workshops, selling farm produce, food aid, or small loan from the government (or governmental organizations), NGOs, or farmers' organizations.

In Liberia and Senegal, amid little presence of such assistance from outer villages, about four Liberian and five Senegalese of every ten surveyed households expected community support akin to those mentioned above.

Access to agriculture-related information helped farmers keep weather, crop and livestock price, food price, and other essential knowledge up to date. The communication channels were not limited to televisions, radios, and newspapers but in-person communications with extension officers, market women, traders, or market wholesalers. Despite the undependable amount of Senegal responses, 71% of Ghanaian and 37% of Liberian families had access to such info.

Yet leaving the other binary variables (land-related conflict and climate-change information) unexplained, count variables came forth for additional predictor information. Bear in mind that no farmer in the study uses advanced technology. Interpretatively, farming households must depend on a certain extent of labor power, and presumably, more labor would yield higher crop productivity, all else being equal. Note that count variables were treated as continuous variables to run decision-tree models.

Outside workers and family laborers were complements rather than substitutes. But in Senegal, no strong presence of outside workers was in the field (minimum=median=0, mean=2, and maximum=100). Instead, farming households counted on more family laborers for farm production (minimum=0, median=5, mean=7, and maximum=40) than Ghana (minimum=1, median=3, mean=4, and maximum=24) and Liberia (minimum=1, median=2, mean=3, and maximum=15). Ghanaian and Liberian households employed more outside laborers, i.e., (minimum=0, median=12, mean=15, and maximum=100) and (minimum=0, median=8, mean=14, and maximum=60), respectively.

A vital distinction of Liberia from the other two countries was *Kuu*. These intimate, small-sized, and time-honored co-operative groups facilitate planting and harvesting that demand more labor power than other tasks in every cropping season (Kolkmeyer, 1970).

Feeding members (dependents) were too young or old to add human resources on any on-farm, off-farm, or animal-raising activities. Counting each one helped us to understand the relationship with food security. In Liberia, a prolonged civil war brings out the asymmetric age-demographic structure. In the 2020 estimate – 65-year-and-older Liberians constitute less than three percent of the population (i.e., 143,694/5.073 million). On the other end of the age spectrum, zero-to-fourteen years of age take up over 43% or 2.199 million, comparable with Ghana at 37% or 10.986/29.34 million, and Senegal in 40% or 6.35/15.74 million. Liberia's median age-group is only 18 years, and that number is 3.4 years and 1.9 years younger than in Ghana and Senegal, respectively. The population growth rate is 2.71% in Liberia, 2.31% in Senegal, and 2.15% in Ghana (Central Intelligence Agency, 2018). In the surveyed areas, rural Liberian dependents were zero minimum, median of four, mean of five, and a maximum of 17. Analogously, Ghana had the same minimum number, a lower median, and a mean of three with a maximum of 13. Across the diverse religious background of traditional, Christianity, and Islam in Liberia and Ghana, Senegal is a preeminent Islamic country. Possibly, a maximum of 69 reflected family composition based on the religious background (despite sharing the same minimum, median, and mean with Liberia).

The predictor 'animal consumption' showed the uniqueness of Senegal. Although Ghana and Senegal had income incurred by animals sold, the ex-post survey revealed a separate livestock count per household to mitigate food insecurity. They seemed correlated but rather distinctive. First, animal income was in USD that considers all disposed small, medium, and large-sized animals. But to measure animal consumption, another question was the number of medium to large-sized livestock (cattle, sheep, and goat) that enhanced nutrition during the worst times or worst cropping season. The count delivered separate information from protein consumption through market items. Of the total 510 Senegalese households, the minimum animal consumption remained zero but expanded to the median three, four of mean, and 34 heads as maximum.

Constraints and technology could cause crop yield and food security in the opposite direction. To explain restrictions, a question in the questionnaire asked reasons for the following that precipitate food shortage. Those explanations included crop failure, poor soil quality (or soil erosion), scarce labor resources, disease/illness, no funds for fertilizer (and insecticide, herbicide), employment loss, conflicts, and multiple other issues not listed. Across the rural communities, the minimum constraint was zero but lower median and mean for Ghanaian households (both two constraints) than Liberia (median=2, mean=3) and Senegal (mean=median=3). Liberia's maximum constraints were (=10), compared to the others (=9).

In Liberia, surveyors could not find the same scope and scale of agricultural technology as Ghana and Senegal. As Sohoulande Djebou et al. (2017) recognized, Ghana's and Senegal's technologies were unlikely the same, both measured differently. Throughout all four Ghana districts, each use of technology, which encompassed irrigation, traditional and upgraded crop storage, tractor, milling machine, hand tool, animal power, and farming-related fuels, counted separately and then added to a whole household. The minimum use was one (that of hand tools) with a median and mean of three, then up to six.

Senegal's technology was in four orders. The basic level indicated the use of only hand tools. The intermediate level embraced a cohort that applied hand tools, animal power, and adequate labor power. Continuing, a high-level of technology use took all the described and substituted animal power for tractor, milling, or other kinds of machinery used. The advanced technology embodied the above, plus storage or irrigation systems, to secure food and water crops in a drought at the highest level.

The last summary statistics below are nominal categories of the surveyed regions. A pursued equal proportion of each area, Ghana divided into 168 households in East Mamprusi in the Northern region, 155 in Atwima-Nwabiagya, 154 in Ejura-Sekyedumase, and 167 Ga West districts. For Liberia, there were 104 households in Grand Bassa, 109 Lofa, and 110 Nimba counties. Senegal offered more regions for a survey, 103 families in Tambacounda, 105 in Kolda, 100 in Kaffrine, 100 in Fatick, and 102 in Matam.

Table 2.2 Ghana Food-security Variables

Variable	Role	Measurement	Summary	Description
Food security	Target	Binary	0 = Food insecure (Freq. = 277) 1 = Food secure (Freq. = 367)	The number of households in food-insecurity and food-security
Household income (US$)	Info.	Continuous	Min. = 24.17 Median = 1547.89 Mean = 1736.05 Max = 8336.92	Total income amount of three components below; for general information instead of a predictor

Table 2.2 Continued

Variable	Role	Measurement	Summary	Description
Crop income (US$)	Predictor	Continuous	Min. = 0 Median = 1024.94 Mean = 1266.82 Max = 8326.42	Crop income
Off-farm income (US$)	Predictor	Continuous	Min. = 0 Median = 204.93 Mean = 340.64 Max = 5604.83	Income not directly from crop income
Animal income (US$)	Predictor	Continuous	Min. = 0 Median = 68.22 Mean = 128.66 Max = 2593.02	Animal income
Credit (US$)	Predictor	Continuous	Min. = 0 Median = 60.09 Mean = 74.09 Max = 2263.97	Total amount credited during the recent crop cycle
Fertilizer (US$)	Predictor	Continuous	Min. = 0 Median = 96.03 Mean = 172.58 Max = 1842.04	Total amount spent on fertilizer
Herbicide/ Insecticide (US$)	Predictor	Continuous	Min. = 0 Median = 36.74 Mean = 79.12 Max = 2545.26	Total amount spent on herbicide and insecticide
Money spent on food per month (US$)	Predictor	Continuous	Min. = 0 Mean = 115.22 Median = 119.39 Max = 367.36	Monthly total amount spent on food items for additional nutrients
Gender	Predictor	Binary	0 = Female (Freq. = 169) 1 = Male (Freq. = 475)	Female or Male head of household
Land conflict	Predictor	Binary	0 = No (Freq. = 470) 1 = Yes (Freq. = 174)	Whether experienced any land-related disputes

Table 2.2 Continued

Variable	Role	Measurement	Summary	Description
Selling channel	Predictor	Binary	0 = No (Freq. = 268) 1 = Yes (Freq. = 376)	Whether crop(s) sold in the village or through more diversified channels
Exogenous assistance	Predictor	Binary	0 = No (Freq. = 287) 1 = Yes (Freq. = 357)	Whether local governments/NGOs/farmer's organizations provided any training workshop, selling farm produce, or food support to households or not.
Agriculture-related information	Predictor	Binary	0 = No (Freq. = 185) 1 = Yes (Freq. = 459)	Whether households' access to weather, farm-product or market information from market women, TV, radio, newspaper, or others or not
Drought/ Flood	Predictor	Binary	0 = No (Freq. = 379) 1 = Yes (Freq. = 265)	Whether drought or flood in climate change interrupted farming practice
Outside labor	Predictor	Count	Min. = 0 Median = 12 Mean = 15 Max = 100	The number of outside laborers (not affiliated with family)
Family labor	Predictor	Count	Min. = 1 Median = 3 Mean = 4 Max = 24	The number of family laborers
Feeding (dependents)	Predictor	Count	Min. = 0 Median = 3 Mean = 3 Max = 13	The number of dependents (subject to be fed either too young or old)
Constraints	Predictor	Count	Min. = 0 Median = 2 Mean = 2 Max = 9	Accumulated count for farming or food-security constraints among crop failure, poor soil quality, insufficient labor, disease, no funds for fertilizer (and insecticide, herbicide), no proper technology, loss of employment, conflicts, and others

Table 2.2 Continued

Variable	Role	Measurement	Summary	Description
Technology	Predictor	Count	Min. = 1 Median = 3 Mean = 3 Max = 6	Accumulated count for farming-technology use among irrigation, traditional and improved storage (separate count), tractor, milling machines, hand tools, animal power, and farming-related fuels
District	Predictor	Nominal	Northern = 1 (Freq. = 168) Atwima = 2 (Freq. = 155) Ejura = 3 (Freq. = 154) Ga West = 4 (Freq. = 167)	Nominal categories to distinguish four districts

Table 2.3 Liberia Food-insecurity Variables

Variable	Role	Measurement	Summary	Description
Food insecurity	Target	Ordinal	1 = Severely insecure (Freq. = 129) 2 = Moderately insecure (Freq. = 112) 3 = Mildly insecure (Freq. = 82)	The number of households in the level of food insecurity
Household income (US$)	Info.	Continuous	Min. = 0 Median = 347.51 Mean = 553.23 Max = 3789.84	Total income amount of three components below; for general information instead of a predictor

Table 2.3 Continued

Variable	Role	Measurement	Summary	Description
Crop income (US$)	Predictor	Continuous	Min. = 0 Median = 250.29 Mean = 434 Max = 3789.84	Crop income
Off-farm income (US$)	Predictor	Continuous	Min. = 0 Median = 0 Mean = 119.24 Max = 1799.60	Income not directly from crop income
Credit (US$)	Predictor	Continuous	Min. = 0 Median = 27.58 Mean = 64.70 Max = 965.30	Total amount credited during the recent crop cycle
Gender	Predictor	Binary	0 = Female (Freq. = 112) 1 = Male (Freq. = 211)	Female or Male head of household
Swamp	Predictor	Binary	0 = No (Freq. = 236) 1 = Yes (Freq. = 87)	Natural land irrigation prepared faming swamp (lowland) rice possible.
Community support	Predictor	Binary	0 = No (Freq. = 196) 1 = Yes (Freq. = 127)	Whether community-wide help was available or not.
Land-related conflict	Predictor	Binary	0 = No (Freq. = 242) 1 = Yes (Freq. = 81)	Whether households experienced land-related conflict or not.
Selling channel	Predictor	Binary	0 = No (Freq. = 148) 1 = Yes (Freq. = 175)	Whether crop(s) sold in the village or through more diversified channels
Agriculture-related information	Predictor	Binary	0 = No (Freq. = 204) 1 = Yes (Freq. = 119)	Whether households accessed to weather, farm-product or market information from market women, TV, radio, newspaper, or others or not
Kuu	Predictor	Count	Min. = 0 Median = 8 Mean = 14 Max = 60	The number of informal co-operative and outside laborers (not affiliated with family)

Table 2.3 Continued

Variable	Role	Measurement	Summary	Description
Family labor	Predictor	Count	Min. = 1 Median = 2 Mean = 3 Max = 15	The number of family laborers
Feeding (dependents)	Predictor	Count	Min. = 0 Median = 4 Mean = 5 Max = 17	The number of dependents (subject to be fed mostly too young)
Constraints	Predictor	Count	Min. = 0 Median = 2 Mean = 3 Max = 10	Accumulated count for farming or food-security constraints among crop failure, poor soil quality, insufficient labor, disease, no funds for fertilizer (and insecticide, herbicide), no proper technology, loss of employment, conflicts, and others (multiple other issues count separately)
County	Predictor	Nominal	Grand Bassa = 1 (Freq. = 104) Lofa = 2 (Freq. = 109) Nimba = 3 (Freq. = 110)	Nominal categories to distinguish three counties

Table 2.4 Senegal Food-insecurity Variables

Variable	Role	Measurement	Summary	Description
Food insecurity	Target	Ordinal	1 = Severely insecure (Freq. = 167) 2 = Moderately insecure (Freq. = 230) 3 = Mildly insecure (Freq. = 113)	The number of households in the level of food insecurity
Household income (US$)	Info.	Continuous	Min. = 0 Median = 1112.93 Mean = 1343.23 Max = 5809.59	Total income amount of three components below; for general information instead of a predictor
Crop income (US$)	Predictor	Continuous	Min. = 0 Median = 938.40 Mean = 948.58 Max = 2153	Crop income
Off-farm income (US$)	Predictor	Continuous	Min. = 0 Median = 0 Mean = 198.59 Max = 2641.89	Income not directly from crop income
Animal income (US$)	Predictor	Continuous	Min. = 0 Median = 6 Mean = 196.07 Max = 1997.61	Animal income
Credit (US$)	Predictor	Continuous	Min. = 0 Median = 0 Mean = 138.55 Max = 2996.81	Total amount credited during the recent crop cycle
Zakat and *Sadaqah* (in Kg.)	Predictor	Continuous	Min. = 0 Median = 140 Mean = 167 Max = 850	Donated or offered staple crops derived from religious faith
Gender	Predictor	Binary	0 = Female (Freq. = 114) 1 = Male (Freq. = 396)	Female or Male head of household
Community support	Predictor	Binary	0 = No (Freq. = 249) 1 = Yes (Freq. = 261)	Whether community-wide help was available or not.

Table 2.4 Continued

Variable	Role	Measurement	Summary	Description
Selling location	Predictor	Binary	0 = No (Freq. = 401) 1 = Yes (Freq. = 109)	Whether crop(s) sold in the village or outside
Outside labor	Predictor	Count	Min. = 0 Median = 0 Mean = 2 Max = 100	The number of outside laborers (not affiliated with family)
Family labor	Predictor	Count	Min. = 0 Median = 5 Mean = 7 Max = 40	The number of family laborers
Feeding (dependents)	Predictor	Count	Min. = 0 Median = 4 Mean = 5 Max = 69	The number of extended dependents (subject to be fed mostly too young and likely outside laborers)
Animal consumption	Predictor	Count	Min. = 0 Median = 3 Mean = 4 Max = 34	The number of livestock (cattle, sheep, and goat) that slaughtered for family nutrition.
Constraints	Predictor	Count	Min. = 0 Mean = 3 Median = 3 Max = 9	Accumulated count for farming or food-security constraints among crop failure, poor soil quality, insufficient labor, disease, no funds for fertilizer (and insecticide, herbicide), no proper technology, loss of employment, conflicts, and others (multiple other issues count separately)

Table 2.4 Continued

Variable	Role	Measurement	Summary	Description
Technology	Predictor	Ordinal	0 = Basic (Freq. = 208) 1 = Intermediate (Freq. = 231) 2 = High (Freq. = 59) 3 = Advanced (Freq. = 12)	The basic level indicates no more than the use of hand tools. The intermediate level indicates hand tools, animal power, and sufficient labor power. The high level indicates most of the above applications and substitutes animal power for tractor, milling, or other kinds of machinery used. The advanced level takes all the above plus traditional/improved storages or irrigation applications.
Region	Predictor	Nominal	Tambacounda = 1 (Freq. = 103) Kolda = 2 (Freq. = 105) Kaffrine = 3 (Freq. = 100) Fatick = 4 (Freq. = 100) Matam = 5 (Freq. = 102)	Nominal categories to distinguish five regions

2.6 First Area-to-Area Comparisons

Nationwide comparisons were available and continued more in-depth, specifically area-to-area and male-to-female-headed households.

The first remains yet interpreted in summary statistics. As described, crop income accounted for more than 70% of rural communities' economies. Land conflict or any land-related disputes could emerge from either irregular weather patterns or land development, or both factors. More rain or prolonged dryness than expected rainy and dry seasons could disrupt the growth and development of crops. In diverse climate and ecological zones, Ghana has experienced widespread floods to drought. Dickinson et al. (2017) examined the Kassena-Nankana district in the Northern region that is up north facing the border between Ghana and Burkina Faso and reported two significant highlights. One, the Northern region delayed the peak rainy season about a month, likely June to July, and compared to the last 10-35 years, rainy seasons in the latest three-to-five years were drier because of lower rainfall in the peak. Two, deforestation could further make farmland dehydrated with the more frequent wind.

Nationwide, Ghana's average rainfall differed from one period to another. The later period of 1991-2016 had 36.85mm less than the earlier period of 1961-1990. The difference between 1152.68mm and 1189.53mm was alarming changes in month-to-month comparisons. The most significant gap was June between the two periods, i.e., -22.36mm or 160.41mm versus 182.77mm. Less rainfall in rainy seasons continued in July (-9.64mm), August (-2.22mm), and September (-9.98mm). However, October in the later period had more rain (+15.22mm or difference between 131.95mm and 116.73mm), and the fact turned out a deferral of (later) rainy seasons (World Bank, 2020h, 2020i). The described characteristics of pervaded survey information.

From the south, 56% or 94 of 167 (farming households) of Ga West experienced more rain, and to the farthest north of Ghana, 43% or 72 of 168 in East Mamprusi of the Northern region had more drought. In between, 39% (or 60 of 154 Ejura-Sekyedumase respondents) and 25% (or 39 of 155 Atwima-Nwabiagya) struggled with the effects of erratic weather. Incoherently, flood or drought seemed not to be an immediate cause of land-related conflict.

Compatible with a survey question, the definition of land-related conflict stayed the occurrence of any minor and significant disagreement over farmland for the last five years to the survey date.

Kemausuor et al. (2011) heard from 150 farmers in Ejura-Sekyedumase, who had over a decade of farming practices, informed more than 80% and 90% realized warmer temperature, unexpectable rainfall patterns triggered by drought. Even with the similar findings above, the district had the lowest frequency of land-related conflict (10% or 16 of 154). Note that all column chart information is available in the Appendix.

In like manner, farming households in the Northern region merely 12% (20 of 168) encountered such conflict regardless of frequent drought exposure. Mixed correlations were observed for the other two districts. Ga West (40% or 67 of 167) and Atwima-Nwabiagya (46% or 71/155) had more households to report land disputes, but it is unclear whether land disputes were related to erratic weather.

Liberia differed from Ghana, despite similar perceptions of climate change in the Northern region of Ghana and rural Liberia. Dickinson et al. (2011) earlier addressed that Ghanaian Northerners perceived any positive or negative weather changes are on *God's hands* and *will*. In Liberia, religious comments centered on natural irrigation. Farmers repeated *God's blessings* to convert barren land moist during the entire cropping season. Often circulated "swamps" made more cultivation of lowland rice that grew well on inundated land.

Land-related conflict and natural land conversion appeared related. In Nimba, 38 and 45 households responded to land disputes and swamps. Lofa had lower frequencies of 35 and 32 but higher than Grand Bassa's eight and ten.

Land tenure and resolution of land disputes seemed indispensable to lasting peace in post-conflict Liberia. Vinck et al. (2011) addressed 25% of Liberians (1125/4501 respondents) who experienced land-related conflicts during and after the civil war. When a specific land-dispute case caused by either (farmland) possession, boundary set-up, or inheritance arose, both claimants tended to rely on village or town chiefs as mediators.

In the absence of statutory laws and systems, neither community residents nor migrants were aware of acquiring, defending, and managing land (Corriveau-Bourque, 2010). As farmland's worth continues to vary with crops and their harvest amount, likely land-related disputes will remain complicated and affect reconciliation efforts (Bruch et al., 2009). Over time, doubtful community management could ruin farmland and devastate land productivity (Hardin, 1968). Among all probable cases, more reasonable victims of land-related disputes could be female-headed households that are socially and communally vulnerable (Ahn et al., 2020; Doss et al., 2018). In many cases in other developing countries, the land belongs to the community as a public instead of private property, which causes farmers without collateral to continue to borrow money with high interests. To the community, simultaneously, haphazard management of land as an asset would hinder investment for land and community development ("Land Reform: Who Owns What?" 2020).

Dichotomous information varies among districts, counties, and regions. Accessibility to exogeneous assistance and community support could mitigate food insecurity.

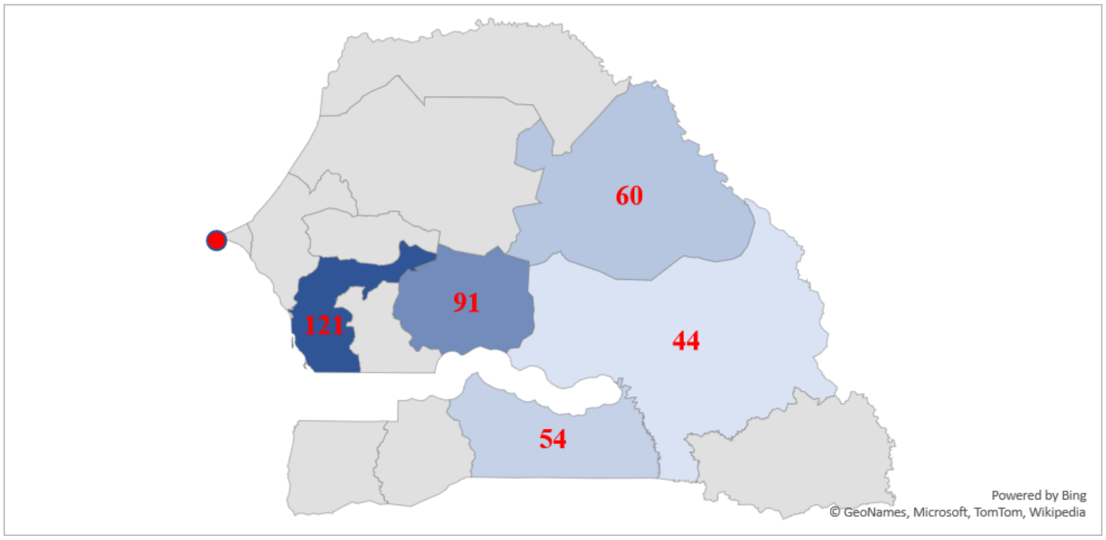
In Ghana, out of 644 households, Atwima-Nwabiagya (n=250) recorded the smallest votes of exogenous assistance, agriculture-related information, and selling channels across the Northern region (n=311), Ga West (n=315), and Ejura-Sekyedumase (n=316). Horizontally, the Northern region (n=95) received more external assistance than Ga West (n=94), Atwima-

Nwabiagya (n=90), and Ejura-Sekyedumase (n=78). The upper north also had the highest frequency of agricultural information (n=137) besides Ejura-Sekyedumase (n=127), Ga West (n=112), and Atwima-Nwabiagya (n=83). However, Ejura-Sekyedumase (n=111) and Ga West (n=109) diversified their selling routes compared to the Northern region (n=79) and Atwima-Nwabiagya (n=77).

Liberia and Senegal showed differences among locations. In Liberia, Nimba (n=171) had more agricultural information, selling channels, and community support than Lofa (n=164) and Grand Bassa (n=86) out of 323 households. Additional households in Nimba (n=48) could access agricultural information somewhat better than Lofa (n=42) and Grand Bassa (n=29). As well, selling channels were wider open to Nimba (n=72) compared to Lofa (n=65) and Grand Bassa (n=38). Lofa households (n=57) received slightly more community support than those in Nimba (n=51) and Grand Bassa (n=51).

Due to insufficient information, we omitted Senegal agricultural information. Regardless, the availability of selling location and community support differed significantly from proximal to distant from Dakar, Senegal's capital. Figure 2.2 is another map of Senegal showing a sum of both counts, and the blue shades turn the darkest, lighter, and lightest corresponding to Dakar's location that is the farthest left or westerly point. The darker blue had more selling location and community support. The darkest blue represents Fatick (n=121), the darker blue, Kaffrine (n=91), two lighter blues in upper Matam (n=60), bottom, Kolda (n=54), and the lightest, Tambacounda (n=44).

Figure 2.2 Selling Location and Community Support (Senegal)



Note. Red dot indicates the capital, Dakar.

Ba et al. (2017) and Vives (2017) explained a pattern of migration. To Europe, Senegalese voyage to the Canary Islands, an archipelago of Spain in northwest Africa (Vives, 2017). Senegalese also migrate into the delta of Dakar or closer to the area when extreme weather conditions interrupted farming in Senegal's interior. In five years, from 2008 to 2013, internal migration continued from Kolda and Tambacounda in polyculture to Kaffrine and Fatick.

Matam lies on the upper Senegal River and is impoverished, isolated, and impassable. FAO (2016) outlined that climate shocks make rainfed agriculture of cereal crops (millet and sorghum) and a legume crop (peanut) more laborious. Specifically, little or no rain in winter 2011 left more than 800,000 residents in the region, Kolda, and Zinguichor with severe food insecurity (World Food Programme (WFP), 2014). WFP (2014) underscored the food crisis affected more in Tambacounda and Kedougou. Between Kolda and Tambacounda, residents migrated back and forth and farther beyond the two regions, although the others in Matam could not (Ba et al., 2017).

FAO (2016), likewise described earlier, added the influence and significance of the community function. The role was not limited to residents' protection to mitigate famine and food shortage, but the community's egalitarian decision-making process could enhance food security over the long run.

Multiple continuous variable information was available by area/location and gender. For four Ghana districts, crop income was higher than animal and off-farm income. Ejura-Sekyedumase, whose primary production was maize, eggplant, and several leguminous crops including beans and cowpeas, had $205 (minimum), $1,028 (Q1), $2,280 (Q3), $1,555 (median), and $3,956 (maximum). The most significant outlier was $8,326. Note that we kept all outliers because, by definition, those individuals deviated from the regular and overall pattern could still influence statistical calculations and their interpretations (Moore et al., 2009, pp. 129-132). The deletion of individual outliers with no apparent justifications causes not only losing observations but misleading predictions.

Atwima-Nwabiagya had a minimum of $351, the first (Q1=$836), the third quintile (Q3) of $1,920, a median of $1,060, and a maximum of $3,491. Atwima-Nwabiagya's farmers grew and provided more crops, including maize, cocoa, palm, tomato, okra, yam, and cocoyam. All referred boxplot information is available in the Appendix. Comparatively, Ga West's crop income went from a minimum of $109, lower amounts of the first (=$656), and the third (=$1,659) quintiles, and between the quintiles, a median of $1,165 was. The highest crop income was $6,034. Like Atwima-Nwabiagya, farmers in Ga West grew a diversity of crops, including maize, cassava, plantain, rice, and vegetables (okra, tomato, pepper, lettuce, carrot, cabbage, cucumber), and palm fruit.

The Northern region recorded the lowest minimum of zero, Q1 (=$186), Q3 (=$791), and a medium of $382 compared to other regions. The maximum amount (=$1,729) and the most massive outlier (=$2,530) were the smallest among the regions. The outlier farming household had maize, millet, cowpea, okra, leaf vegetables, and raised cattle, sheep, goats and chickens. Additionally, nine cotton farmers marked a higher income distribution between $1,028 and $2,177.

To the north, the animal is essential not for adding income but for supporting agricultural production. Out of 168 households, 133 responded to plowing the land using animal power and tractors. Small animals like chickens and guinea fowls, medium-sized goats and sheep, and relatively larger donkeys and cattle were common in the northern region. The boxplot displays $31, $192, $315, and $761 corresponding to the first quintile, median, the third quintile, and maximum. The outliers were $971 and $2,593.

For the other districts, animal income was not a significant portion of the total household income. Many households in Ga West raised goats and chickens. Some owned sheep, ducks, cattle, turkeys, and grasscutters. Altogether, Ga West followed $52 to $210 with a maximum of $525 and two outlier amounts, $787 and $1,653.

Atwima-Nwabiagya and Ejura-Sekyedumase reached hardly $60 of mean and median, and a maximum of $290.

Off-farm income differed from one district to another. A commonality was closer to the town or city, the higher the off-farm revenue was.

Spatially, Atwima-Nwabiagya and Ga West are near high population density, and delivering farm produce of the residents' and other neighbors together brought a profitable off-farm income (often called traders' profit in local knowledge). Atwima-Nwabiagya had the first quintile of $157 and the third at $771. In between, a median was $385, and the maximum here was $1,050. In Ga West, a range of off-farm revenue ran $8, $420, and $656. Outside the box, were a maximum of $1,522 and outliers of $1,952, $2,440, $4,093, and $5,605.

In East Mamprusi, Gambaga, the district capital is spatially proximate. Off-farm revenue had a range of zero, 186, 354, and 892 dollars, more outliers between 1,260 and 2,999 dollars. Ejura-Sekyedumase earned less off-farm revenue overall, between zero and 525 dollars.

Liberia's household income was lower than its counterpart Ghanaian households. Between Lofa and Nimba, ranges of farm income were similar. However, Nimba's first and third quintiles were $71 and $36 more than Lofa's, i.e., $164, and $93, $660, and $624. The median in Nimba of $363 was $110 higher than Lofa's, $253. In both counties, five to six outliers each were between $1,557 and $3,790. The outliers represented commercial farmers who supply coffee, vegetables, and other cash crops to Lofa county's district capital, Voinjama, and border Guinea. In Nimba, farmers sold coffee and other similar valuable crops to its district capital Sanniquellie, and a few grew rubber trees to meet Firestone's demand.

Lofa and Nimba have been Liberia's breadbaskets whose rice and cassava production is the highest (De La Fuente et al., 2019). Assuming Grand Bassa's lower farm income $39 (Q1), $160 (median), $474 (Q3), and $1,086 (maximum) were reasonable. Nor were two outlier cases ($1,345 and $1,496) more than Lofa and Nimba.

Making and selling charcoals, hunting bushmeat, processed palm oil, palm wine, and sugarcane juice was primary off-farm income sources/products. Although Grand Bassa and

Nimba had similar kinds shown in outliers between $25 and $1,050 (further $1,738), Lofa only shaped a semi-box in $234 (Q3) and a maximum of $496. Beyond that, eight outliers were $745 to $1,800.

Senegal presented crop, off-farm, and animal income in USD for five regions. Amid Djilas in Fatick held the highest crop income $864 (Q1), $1,134 (median), $1,503 (Q3), and $2,153 (maximum) in a boxplot, Nguerane Fass in Kaffrine appeared the next, $251 (minimum), $751 (Q1), $1,115 (median), $1,370 (Q3), and $2,103 (maximum). Among Waoundé in Matam, Sadatou in Tambaounda, and Dabo in Kolda, the first two showed a similar shape and range. In sharing the same zero minimum, the first quintile of Matam (=$529) and Tambacounda (=$533) differed only four dollars, the 14-dollar difference in the third quintile between Matam (=$1,144) and Tambacounda (=$1,130). Despite the similarity, the median and maximum had a bigger gap for Matam (=$898, $1,948) and Tambacounda (=$839, $1,624). Kolda had two outliers of $1,747 and $1,693 in crop income. The maximum was smaller than the other four regions (=$1,484), as were Q3 (=$933), median (=$723), and Q1 (=$540). However, Kolda (=$245) and Kaffrine (=$251) were the only regions whose minimums were not zero dollars.

For off-farm income, no comparison was possible in a transparent boxed shape. Matam had a higher maximum off-farm income (=$799), the third quintile (=$400), and the median (=$43). Eight outliers were between $999 and $1,998. Fatick's nine outliers had a more comprehensive range of $899 and $2,642. Lower, a maximum (=$739), Q3 (=$300), and median (=$30) all were less than Matam's. Tambacounda comes next with a maximum (=$438), Q3 (=$200), and nine outliers from $500 to $1,957. The amounts of off-farm income in Kolda (maximum=$200 and Q3=$80) and Kaffrine (maximum=$80 and Q3=$40) were, and the outlier range was $100 and $1,359.

Animals, together with farm equipment, were the essential rural household assets. When drought and further food insecurity came, a typical arrangement was to dispose of small-sized (chicken) and medium-sized animals (goats and sheep). If the complication persisted, rural Senegalese households sold farm equipment, cattle, and jewelry. Massive migration ensued if the precedents could not mitigate hunger, further causing a decrease of households and animals (FAO, 2016; Taal, 1989).

In comparison, Tambacounda recorded the highest animal income (maximum=$1,001, Q3=430, median=$94). More than the maximum, six outliers were between $1,200 and $1,998. Matam was next in earning with a maximum of $500 and the third quintile of $202. Like its former comparison, seven outliers had an extended length of disconnected dots between $600 and $1,995. A broken box continued in Kolda (maximum=$400, Q3=$185, median=$25) that a maximum amount was lower than Tambacounda's and Matam's. Nine outliers were from $490 to $1,557.

Fatick and Kaffrine recorded less animal income than Tambacounda, Matam and Kolda. Fatick showed $206 as the maximum, $93 as the third quintile, and $9 as the median. Twelve cases were outliers in dot-to-dot between $290 and $1,879. Kaffrine had $120 maximum, $43 as its third quintile, and zero dollars.

Quantitative information did not reveal qualitative and unusual data. Those with high off-farm income received financial support from other family members in Dakar or living overseas. In Matam, ten households, whose crops were entirely stolen by granivorous birds, pests, and locust invasion, relied on neighbors' generosity. Also, in Tambacounda, 14 residents reported granivorous birds interrupted harvest. At least four families in Kolda sold assets such as hoes, bikes, and goats to access food.

Other features differentiated one another. Two Kolda farmers provided information that a company named SOFITEX supported seed, fertilizer, and herbicide to grow cotton. The help continued to purchase harvested cotton. But one of the two cotton growers expressed concern about delayed payment. Another farmer recalled all agricultural materials flew through SOFIFEX, whether a farmer grew cotton or not.

Besides remittance from family members in off-farm income, the surveyors met other occupancies, inclusive carriers of wood chips/pieces/sticks or between Mauritania and the upper Senegal river, fishermen, a donut seller, and small businesspeople in Matam,

Some contributed as marabouts in Tambacounda, another marabout and an employee at the Catholic mission in Fatick, and a chief, NGO worker at Tostan in Kolda. In Kaffrine and Fatick, a dozen households facilitated crop storage.

Despite the variation of quantitative and qualitative information in five Senegal regions, one consistent information was *Zakat* and *Sadaqah*. Taal (1989) observed *Zakat* applied for all Muslims, even those in low-income farming households, to offer eight to ten percent of the total harvest. The offering went beyond neighbors in the same village. The obligation continued to kinship outside their residence.

All over the regions, families offered millet, peanuts, sorghum, corn, rice, honey, and cowpea as *Zakat* and donated as *Sadaqah*. Quantitatively, all summed up amount in kilograms, regardless of crop diversity, was for analysis.

Tambacounda's *Zakat* and *Sadaqah* showed the widest gap, that is, Q1 (=44kg), median (=176kg), Q3 (=292kg), and a maximum (=659kg). Three outliers were 675kg, 800kg, and 850kg. Fatick received a higher minimum (=6kg) and Q1 (=120KG) but a lower median (=170kg), Q3 (=248kg), and maximum (=410kg), besides five outliers between 455kg and

588kg. Kaffrine's first quintile (=71kg) was between Tambacounda's and Fatick's, but the others were lower (median=145kg, Q3=206kg, maximum=390kg). Two outliers were 420kg and 495kg.

Matam (Q1=55kg, median=120kg, Q3=190kg, maximum=370kg) and Kolda (Q1=34kg, median=92kg, Q3=182kg, maximum=375kg) were a smaller amount of *Zakat* and *Sadaqah* than the other three comparisons throughout the four-point summary. Outliers were between 420kg and 620kg.

2.7 Male-to-Female-headed Farming Household Comparisons

Male-headed and female-headed households revealed two different incomes. Taal (1989) shared a field observation that female farmers who supplied little labor on swamp rice turn their effort on groundnut production. Ahn et al. (2020) reported the drawbacks of Liberian female-headed households in lower use of *kuu* labor, amount of credit but more frequent land-dispute cases than male-headed families. As a snapshot and single output, each country's gender-headed incomes comprise crops, off-farm in three countries, and animals in Ghana and Senegal.

First, in order, Ghanaian households showed the smallest gap compared to the other two countries. Against male-headed households (minimum=$27, Q1=$1,045, median=$1,679, Q3=$2,402, maximum=$4,375), female-headed families recorded a minimum of $24, Q1 of $863, median of $1,302, Q3 of $1,721, and a maximum of $2,976. Six outliers of the male-headed in $4,618 and $8,337 grouped a higher range than four outliers of the female-headed households between $3,024 and $5,325.

The income gap became wider between male-headed and female-headed households in Liberia. Given the difference in household income between Ghana and Liberia, male-headed families had $10 more in minimum ($10-$0), $203 more in the first quintile ($224-$21), $381 more in medium ($499-$118), and $683 more in maximum ($1,869-$1,186) compared to female-headed families. The outliers between two genders ran a difference of the range $1,906 and $3,790 (male-headed) and $1,290 and $2,105 (female-headed).

In Liberia's agriculture, the role of women seemed fundamental. They supplied 45% of farm produce in 2016, and more (55%) planted rice and cassava than male growers (Liberia Institute for Statistics and Geo-Information Services (LISGIS), 2018). But in comparing the proportion of cash crop production, disproportionately more male farmers (61%) accessed coffee, sugarcane, palm, rubber, and cocoa than did females (39%) (World Bank, 2010).

The growing disparity between two gender-headed households continued in Senegal. Male-headed households earned $360 higher in minimum ($360-$0), $545 more in Q1 ($938-$393), $650 more in median ($1,233-$583), $794 more in Q3 ($1,700-$906), and further $1,085 more in maximum ($2,722-$1,637). Eighteen outliers of male-headed households stood in dot-and-dot between $2,843 and $5,810 but only one outlier female-headed case was $1,898.

2.8 Second Area-to-Area Comparisons

Ghana tended to rely less on credit. Atwima-Nwabiagya's households showed a boxed shape with its third quintile of $160 and a maximum of $399. The only outlier ($404) was similar to the maximum. Except for outlier cases in Ga West, all other amounts were under $400 in the Northern region and Ejura-Sekyedumase. Ga West made the most comprehensive outlier range of $0 and $299 (the first), $795 and $1,215 (the second), and a dot of $2,264 (the third).

Liberia had more frequent use of credit. Combined male- and female-headed households, three counties were in a close range. The median was highest in Grand Bassa (=$44), Nimba in the middle (=$28), and Lofa, the lowest (=$11). For the third quintile and maximum, Nimba (=$101 and $207) was higher than Grand Bassa (=$84 and $196) and Lofa (=$69 and $165). The assortment of outliers in Grand Bassa was narrower between $252 and $331 than Nimba’s $331 and $807, and further Lofa’s $207 and $965.

In Senegal, Kolda, Tambacounda, and Matam accessed limited credit. Matam had the lowest maximum (=$100) and the third quintile (=$52). Out of the boxplot, 14 outliers formed a long tail of $150 to $2,198. Kolda received a higher maximum (=$258) and the third quintile (=$110). Outliers seemed were in dot-and-dot between $300 and $600, besides one dot on top of $1,300. The data points (maximum=$200 and Q3=$99) of Tambacounda were between Matam’s and Kolda’s. Six outliers in Tambacounda were between $280 and $999. One amongst the outliers was in the region, $2,997.

Kaffrine and Fatick were in a similar arrangement. Kaffrine advanced a median of $60, the third quintile of $300, and a maximum of $740. Outliers were $759 and $879. Then Fatick followed the third quintile of $200 and a maximum of $500. Six outliers from the boxplot were from $575 to $1,199.

Credit consists of principal and discrete interest rates. Ghana relied on smaller amounts of credit. In Liberia, female farmers commented in a concerted voice that male farmers accessed additional credit channels and lower interest rates. Consistently, Ahn et al. (2020) claimed that female-headed households tended to obtain credit from susu clubs borne higher interest rates but discontinued or at least less relied on credit as household income grew. Taal (1989) suggested that Senegal's credit was only accessible to more affluent farmers who could borrow from family members, relatives, neighbors, and others through guarantees.

The monetary amount of fertilizer and herbicide/insecticide spent on the district's farmland was available for Ghana. Ejura-Sekyedumase, where agricultural production was mature in survey and farmers were knowledgeable of fertilizer, herbicide, and insecticide, used most financial resources on chemical substance (minimum=$59, Q1=$155, median=$242, Q3=$390, maximum=$737 in fertilizer). Seven outliers of fertilizer were between $748 and $1,419. The total amount incorporates out-of-pocket payments and government vouchers. Ejura-Sekyedumase filed a higher Q1 (=$32), median (=$79), Q3 (=$224), and maximum (=$512). An outlier (=$530) was next to the maximum amount in a boxplot.

Ga West, overall, spent the second-largest amount on fertilizer and herbicide/insecticide. The first quintile of fertilizer was $42, a median of $63, the third quintile of $277, and a maximum of $491. Five outliers ranged from $771 to $1,842. For herbicide/insecticide, the median arose $31, the third quintile of $111, and a maximum of $221. Beyond, three outliers were $259, $302, and $344.

Atwima-Nwabiagya marked a higher median (=$48) and Q3 (=$156) of herbicide/insecticide. The maximum amount (=$219) was similar and only two dollars lower than Ga West. The only outlier in Atwima-Nwabiagya was up to $2,545. Unlike Ejura-Sekyedumase and Ga West, Atwima-Nwabiagya's fertilizer and herbicide/insecticide shaped a similar boxplot (Q1=$48, median=$61, Q3=$162). The maximum was $329, and three outliers were $334, $411, and $490.

To the north, the use of herbicide/insecticide amount was the lowest in Ghana (median=$7, Q3=$63, maximum=$112, and outlier=$262). The amount of fertilizer in the Northern region (Q1=$41, median=$79, Q3=$145, maximum=$299, and outliers of $315 to

$590) was close Atwima-Nwabiagya's. In various combination levels, farmers paid for inorganic, chemical N-P-K fertilizer, and organic fertilizer, including manure and compost.

Information on household consumption, family, and outside workers in a month further explained the household economy. Atwima-Nwabiagya advanced (minimum=$31, Q1=$131, median=$157, Q3=$199, and maximum=$278) among comparisons. Below the minimum, an outlier was $26. Above the maximum, two outliers were $304 and $320.

Ga West recorded the next. Compared to Atwima-Nwabiagya, per component, expenditure on food items was $19 lower in minimum, $52 smaller in Q1, $31 less in the median, $42 lower in Q3, and $10 smaller in maximum (Or minimum=$12, Q1=$79, median=$126, Q3=157, maximum=$268). Four outliers in Ga West were $283, $299, $341, and $367.

Ejura-Sekyedumase farmers expended more than the Northern region, except for the maximum and an outlier. The minimum was $21, $62 for Q1, $105 of the median, $135 for Q3, and $189, maximum. The Northern region expended $21 more than Ejura-Sekyedumase's maximum. However, the other components were lower (minimum=$0, Q1=$28, median=$53, Q3=$104). The only outlier in the Northern region was $262.

Additional count information of Ghanaian household dependents, family laborers, and outside workers is provided here before method explanations.

Across four districts of Ghana, the maximum number of dependents was highest in the Northern region (=9 members), followed by Ejura-Sekyedumase (=8), Atwima-Nwabiagya (=7), and Ga West (=6). Two outlier counts were 10 and 13 members in the Northern region. Below, Q3, the median, Q1, and the minimum look-alike in four, three, and zero members.

For a summary of family laborers across districts, the Northern region consistently had more (maximum=13 laborers, Q3=8, median=5, Q1=4, minimum=1). Four outliers not in the boxplot were 15, 19, 22, and 24 laborers.

With the same minimum, Ejura-Sekyedumase formed two-family laborers as Q1. A median, Q3, and maximum were four, five, and eight.

Ga West had two outliers (12 and 8) over a maximum of seven family laborers. At the third quintile, median, the first quintile, and minimum were four to one with one person's interval.

Atwima-Nwabiagya employed the least number of family laborers. From the maximum to a minimum, a person's interval continued four, three, two to one.

Farmers in Atwima-Nwabiagya worked with the highest number of external workers (maximum=40, Q3=27, median=20, Q1=16, minimum=7). Nine outliers over the maximum were between 44 and 77.

Ejura-Sekyedumase showed the most extended interval from zero to 100 outside workers. Forty to a hundred made nine outliers. And below forty, 39, 19, 14, six, and zero formed the maximum, Q3, median, Q1, and minimum, respectively.

Ga West's boxplot was located under Atwima-Nwabiagya's and Ejura-Sekyedumase's. Three outliers were 52, 42, and 32, and below, the maximum, Q3, median, Q1, and minimum were 30, 16, 11, six, and zero outside workers.

The Northern region retained the least number of outside workers. Four outliers were 41, 30, 28, and 26. Under the range, the maximum, Q3, and median were 25, 10, and five. The first quintile and the minimum were zero.

Count variables further reflected Liberia. Between zero and 17 dependents, three counties showed a small variation. Only Grand Bassa had two outlier cases of 17 and 11 dependents. Lofa shaped the highest number of dependents (=12) in a boxplot as a maximum, below the third quintile of seven, the median of four, and two in the first quintile.

The boxplot of Grand Bassa was smaller (maximum=10, Q3=6, median=5, Q1=3) than Lofa, and below Nimba's was (maximum=9, Q3=5, median=3, Q1=2). In all counties, cases were zero dependents.

Currens (1976) and Ahn et al. (2020) witnessed Liberia's rice production-maintained slash (trees)-and-burn small acreage of forest and brush-and-clear the area for planting rice. While rice grew, weeding, scaring off grain-theft birds, or fencing or trapping to prevent the rice consumption or destruction from other animal pests. After harvest, more processes (threshing, winnowing, milling, bagging) and transporting rice to the wholesaler, trader, or market merchant. More intensive laborers should be timely and appropriate amid lacking agricultural technologies. In four decades, from 1972 to 2012, no noticeable technological change or advancement had occurred.

Depended on the field observations and literature on labor-intensive agricultural production in Lofa and Nimba as Liberia's breadbaskets, and Grand Bassa, more family- and *kuu* laborers could directly boost agricultural produce, ceteris paribus.

Lofa, Nimba, and Grand Bassa shared a similar proportion of family laborers. Across the maximum, Lofa (=8) had two additional family laborers than Nimba (=6) and Grand Bassa (=6). The sequence remained the same for the third quintile (Lofa=4, Nimba=3, Grand Bassa=3). One additional layer below Lofa and Nimba had two family laborers as the median but only one in Grand Bassa.

Moving to *kuu*, informal outside workers, the number became distinctive across the counties. The maximum count was 60 *kuu* members in Lofa and Nimba. Too, the third (upper) quintiles were the same at 28 workers in both counties. The first difference appeared in the medium. Lofa (=15) had two additional *kuu* members to Nimba (=13). Again, two counties merged in the lower quintile (Q1=5).

Grand Bassa's boxplot displayed a different distribution. Four outliers over the maximum were 36, 33, 25, and 20 members. The maximum was 19, and further down to eight members as the third quintile (Q3). The medium was three members, and Q1 and a minimum were zero.

Senegal had fewer outside workers than the other countries. Matam was the only district barely structured a boxplot with a maximum of 10 and below the third quintile of four workers. Others formed seven outliers over the maximum between 12 and 100. The next outlier range was in Tambacounda between one and 52, followed by Kaffrine from one to 33. Kolda had smaller outliers between one and 20. Fatick had only one household that worked with an outside worker. Clearly, the boxplot showed Senegalese farming households relied more on family labor. Kaffrine had 20 family laborers in maximum, 10 in Q3, six in the medium, and three in the lower quintile (Q1). An outlier was 31. In comparing maximum-to-maximum, Matam (=18) came afterward. Together with outliers (=21, 24, 29), the third quintile was 10, the median, six, and the first quintile, three family laborers.

Fatick had a maximum of 17, and nine (Q3), five (median), three (Q1), and one (minimum). More than the maximum number were 20 and 33 outside workers in the region. Kolda and Tambacounda shared the same median (=5) and Q1 (=3), but Kolda retained more outside workers in maximum (=16) and Q3 (9) than Tambacounda's maximum (=14) and Q3 (=8). Outliers of Kolda were between 17 and 40 against Tambacounda's 19 and 31.

The number of dependents across five regions did not show a significant difference. Matam had more than the others in a range (maximum=21, Q3=10, median=6, Q1=2). Outliers were 25, 28, 40, and 69.

Tambacounda followed with a maximum of 14, Q3 of seven, the median of four, and Q1 of two dependents. Five outliers were between 15 and 29. A worker's difference in maximum brought Kolda to the next place. With a maximum of 13, the third quintile, the median, and the first quintile were six, three, and one dependent member.

Between Kaffrine and Fatick, Kaffrine appeared in a range of the maximum (=11), Q3 (=5), median (=2), and Q1 (=1). An outlier was 16.

Finally, Fatick showed a maximum of 10, the third quintile of five, the median of three, and one dependent in the first quintile. Over the maximum, three outliers were 12, 14, and 17.

A group of predictors in the various binary, continuous, count, and nominal category formats of regional comparisons made the food-security analysis realistic and comparative with decision-tree methods.

2.9 Methods and Procedures

The primary purpose was to understand the different farming techniques, technologies, farm income levels, other income sources, and socioeconomic indicators of food security that differed comprehensive profiles. Nationwide and regional similarities/differences could complicate tailored policy recommendations/implications. This challenging situation made black-box techniques pertinent and validated this study.

The diversity among 1,476 cases created our reluctance to put them in one basket. Based on sample size, separate tree-based models ran under consideration: (1) three countries with at least 323 cases; (2) all simple and straightforward questions and responses; and (3) all exchanged US$ variables and non-financial information. Other considerations include, first, in Ghana's agent case is the maximum preparedness for food insecurity and stable agricultural development. Second, more examples (=643) also empowered a tree-based model to advance a random forest. Third and more importantly, a random-forest classification worked ideally and empirically for the binary target, whose information balanced between food-secure and food-insecure groups (Breiman & Cutler, 2003).

In the family of tree-growing methods, the CHAID algorithm built a single non-parametric decision tree; a random forest allowed as many classification trees as possible to avoid the reliance on a single-tree output.

First, in order, Kass (1980) designed and empirically tested CHAID; then Biggs et al. (1991) adapted it to exhaustive CHAID. CHAID allows only for categorical target variables. Several benefits include:

1. finding and evaluating variables related to significance.
2. tolerating skewness and outliers of continuous variables or categorical variables with many categories, and
3. managing missing information (though not in this case) (Song & Ying, 2015).

Exhaustive CHAID algorithms step the merging-splitting-stopping process many times in growing a tree. Merging matches a group of predictors that gives the highest p-value, the most related, or least statistically significant to the ordinal target *Y* as exhaustive Chi-squared tests (χ^2), among all predictors, that is, $X_m, m = 1, 2, \dots M$. Until a pair of *X* and *Y* that proves maximum similarity, an exhaustive search continues. Suppose *I* and *J* independently represents *X* and *Y* category. Due to the ordinal variable *Y*, two cell counts emerge – one for the null hypothesis of independence or $\hat{m}$; the other for a row-effects model or $\hat{\hat{m}}$. Altogether, the test statistic (TS, unadjusted) and p-value calculations:

$$\boldsymbol{TS} = \mathbf{2} \sum_{i=1}^{I} \sum_{j=1}^{J} \hat{\hat{\boldsymbol{m}}}_{ij} \ln \left(\frac{\hat{\hat{m}}_{ij}}{\hat{m}_{ij}}\right) \quad \textbf{(2.1)}$$

$$\boldsymbol{p - value} = \textbf{Prob}.\,(\chi^2_{I-1} > \boldsymbol{H}^2) \quad \textbf{(2.2)}$$

Splitting then repeats to seek the predictor that affords the most statistical significance based on the adjusted p-value. Multiplying the p-value by the Bonferroni correction makes numerous tests possible at once. The formula of the Bonferroni multiplier β:

$$\boldsymbol{\beta} = \begin{cases} \frac{I(I-1)}{2} & \textbf{Ordinal variables} \\ \frac{I(I^2-1)}{2} & \textbf{Nominal variables} \\ \frac{I(I-1)}{2} & \textbf{Ordinal (with a missing category)} \end{cases} \quad \textbf{(2.3)}$$

When the adjusted p-value becomes smaller than the alpha-split number, splitting ends (Grömping, 2009). After the position flips, stopping appears, the final node stays terminal (IBM, 2019).

The results should be a tree construction and other validations, including misclassification risk estimates of the training and v-fold and their standard errors. V-fold cross-validation breaks all the samples of the training data down into ten groups evenly and randomly. Every round excludes the final fold, and consequently, the average error estimate and standard deviation of in total nine of the 10th folds would be. The ideal case is to keep both classification risk and standard errors in the training and v-fold information low, and further variation between the two minimal.

Random forests were first invented and introduced by Breiman (2000). In theory and practice, the newer method overcame a few persistent problems of single decision trees. Mainly and often, overfitting persists, which caused inadequate validation regardless of well-fitted training data for classification. Here, single decision trees explained the actual knowledge in training data. It was still unlikely to classify new, test-data information (Supposedly, v-fold cross-validation informed determining a reasonable, accurate, and acceptable operation.).

For random forests, the word “random” has three meanings and contributes to the stepwise process:

1. The bagging algorithm creates many random cases *n* (unique bootstrap samples) from training data *N*.
2. Multiple random decision trees or *ntree* by user choice appear from bootstrap samples.
3. A random subset of *mtry* (i.e., square root of all predictor counts) makes every tree split apiece. Suppose total *M* input variables to the most considerable range, $m<<M$ is reasonable at each node where *m* variables of *M* for split-the-node.

More detailed explanations are possible. By default, the algorithm trains precisely 63.2% of all cases with a replacement for the use of individual tree growth. The leftover 36.8% is to calculate the misclassification or out-of-bag (OOB) error rates. For instance, this study selected 150 decision trees (i.e., ntree=150), and accordingly, approximately 95 and 55 trees were for random-tree selection and overall OOB error evaluation, respectively. This internal validation as an unbiased-error estimate requires a minimum effort of cross-validation or such division sampling methods to determine whether the classification is accurate (Breiman & Cutler, 2003).

Randomness leaves many trees unsettled. Altogether, however, the more volatile trees could provide an output that helps better decision-making. Independent trees are separate classifiers and predictors, and a low correlation between trees makes the misclassification rate go down or vice versa. Also, every small error rate or the strength of separate trees counts a reliable, settled forest classification, reflecting most votes from those trees. In turn, the classification accuracy depends on developing an ensemble of *ntree* and a final selection of *mtry* (Grömping, 2009). Curtailing m (input predictors) lowers the correlation and strength (Breiman & Cutler, 2003). Every tree has no limit growing from the root node, and no pruning is necessary.

Proximity is another highlight. It is a square matrix format {prox(n,k)}between cases n and k. Initially, the algorithm sets proximities zeroes. Applying proximities to all instances of every tree begins the matrix up and down between zero and one. Assuming cases n and k reach the identical final node, the proximity between the two would be one (on the diagonal). The other proximity toward zero is possible for the different end nodes (not on the diagonal or off-diagonal). In the end, the total trees have grown and are gathered in a random forest; the proximities become normalized when divided by the same number of trees (Breiman & Cutler, 2003). This operation is to detect outliers or impute missing values.
Imputation was not required for this study, as there were no missing values. But the feature remains essential for observed outliers.

Breiman (2001) and Breiman and Cutler (2003) define outliers such small and often negligent cases that relative proximities or similarities are distant from most others. This situation further formulates. Suppose a class j includes outlier respect to other cases in j class. Then average proximity of case n as:

$$\overline{\boldsymbol{Prox.}}(\boldsymbol{n}) = \sum_{\boldsymbol{d(k)=j}} \boldsymbol{prox^2}(\boldsymbol{n}, \boldsymbol{k}) \qquad \textbf{(2.4)}$$

and basic measure of case *n* outlier as:

$$\frac{\boldsymbol{Number\ of\ Cases}}{\overline{\overline{\boldsymbol{Prox.}}}(\boldsymbol{n})} \qquad \textbf{(2.5)}$$

Both formulae give two calculated values reversed (e.g., average proximity smaller; a raw measure of case *n* outlier high). The relationship seeks the final outlier value, first traces all measures' median and median absolute deviation in each class *j*, then subtract the former to the latter. The division of the amount by the absolute deviation follows to release the final outlier value.

Predictor (variable) importance is a one for attention to report and interpret the results. Per tree, 36.8% of OOB cases let a count of the valid votes toward the correct class; then, one side randomly permutes or arranges the variable *m* values. There are two separate counts, one for (treated) accurate vote counts in the variable-m-permuted OOB information and correct vote counts in the (untreated) OOB data. Subtraction of the treated from the untreated and the average between the difference for all trees would provide variable *m*’s importance score (Breiman and Cutler, 2003). The higher-score predictor or more predictive capability would drive more significance to the target, or vice versa.

The forest would combine 'Yes' votes across all classification trees from OOB data near the end process. Gains curves present the accumulated votes. The vertical y-axis shows the percentage of 'Yes' true-positive (TP) counts, divided by true-positive but false-negative counts. This displays the accumulated probability of right 'Yes' classification from observations and predictions (TP) out of TP plus 'Yes' misclassification originated from predictions (false-negative or type 2 error, FN). On the horizontal x-axis, the proportion is the number of TP, and 'Yes' misclassification emerged from observations (false-positive or type 1 error, FP), divided by all observation counts. Later, together with a confusion matrix for the overall classifier performance, clearer and more straightforward interpretations are possible.

Often, the use of gains curves substitutes for receiver operating characteristic (ROC) curves. Both look visually alike as the y-axis shares the same information. Horizontally on the x-axis, however, gains charts add TP counts on the numerator to FP counts. Still, on the x-axis, ROC curves take only TN and FP on the denominator compared to gains charts that take all observation counts.

The fundamental difference between the two curves is that a gains curve displays based on 'Yes' and food-secure cases. The table below displays different and similar elements to form gains and ROC curves.

Table 2.5 Gains and ROC Chart Construction Elements

	Gains	ROC
Y-axis	$\frac{TP\ counts}{TP\ counts + FN\ counts}$	$\frac{TP\ counts}{TP\ counts + FN\ counts}$
X-axis	$\frac{TP\ counts + FP\ counts}{all\ observation\ counts}$	$\frac{FP\ counts}{TN\ counts + FP\ counts}$

2.10 Results

Out of ‘black boxes’ as decision-tree techniques, a CHAID model for Liberia, two CHAID models for Senegal, and a random forest model for Ghana were reported. In the face of coalescence of predictors for food insecurity/security by the nature of primary data collection, each tree built independently seems complementary. Predictions further suggested the consideration of contexts of three countries in West Africa.

For Liberia, more (=129) households were in severe food insecurity than in moderate (=112) and mild (=82). The results ensued from releasing more predictors for the families in severe. Moving down from the beginning node to the lowest, more than 50% or 84 of 129 households remained to embrace seven predictors (Figure 2.3).

On top of each bar in red, green, and blue represents individual proportions in severely, moderately, and mildly food insecure (Box1). Consistent with these, more reds than greens and blues were (Asterisk (*) atop of a bar signals each node's major food-insecure group.).

The first decision to classify three layers of food insecurity was whether households had village-wide support of food, training, and small loans from village councils. Bartering, sharing, or buybacks food between neighbors amid a shortage of exogenous assistance mitigated the worst period of food insecurity. One-ninety-six (in Box2) against 127 (in Box3) could not expect a range of support in rainy seasons, i.e., May-October or August-September's peak.

Going further down among vulnerable households – capabilities of selling farm produce outside communities bisected decisions between the most severe of food insecurity and the upper levels. Sixty-nine (in Box5), as opposed to 127 in-village sellers (in Box4), were likely to have more moderately food insecurity families (=35 of them against 21 in severity and 13 in mild). The *Selling channel* was a robust predictor, even with awareness of the unequal distribution of household income between genders, classifying 12 mildly insecure female-headed and 11 moderately insecure households instead of four in severe (Box13). The algorithm divided 42 male-headed households into 24 in moderate against 17 in severe and only one in mild under the same branch (Box14). Below to those male-headed households, 23 in moderate and 17 in severe had limited capacity to work with no more than 25 *kuu* members (Box15). Only two of 42 could employ over the threshold of 25 in the other node (Box16).

To those waiting for further explanations in Box4, rainfall land conversion from dryland to *swamps* cut across two nodes, and only 15 had a possibility of growing lowland rice (Box12). *Better* give a possibility for the farmer who was capable of planting to the harvest. Two precedent conditions of diversification of selling channels and community support could make the possibility real. Because of dissatisfaction, only seven were moderate, while the other seven were in severe and another one in mild.

With no natural irrigation, access to agricultural information continued to bifurcate the remainders (a little less than a third of the total, 97 severe, 13 in mid-level, and two in mild in Box11). The 18th node ended with 20 agriculture-information gatherers who were a dozen with severe food insecurity, seven in moderate, and one in mild. On the left, no accessors (=85 severe, six in the middle, and one in mild in Box17) faced another question to split two nodes.

Off-farm income, whose threshold is 330.98 USD, could further divide a household at a moderate level of higher food insecurity to end the node (Box20). The other 91 made less than the reference amount of off-farm income that augmented the total household income, and enhanced food security (Box19).

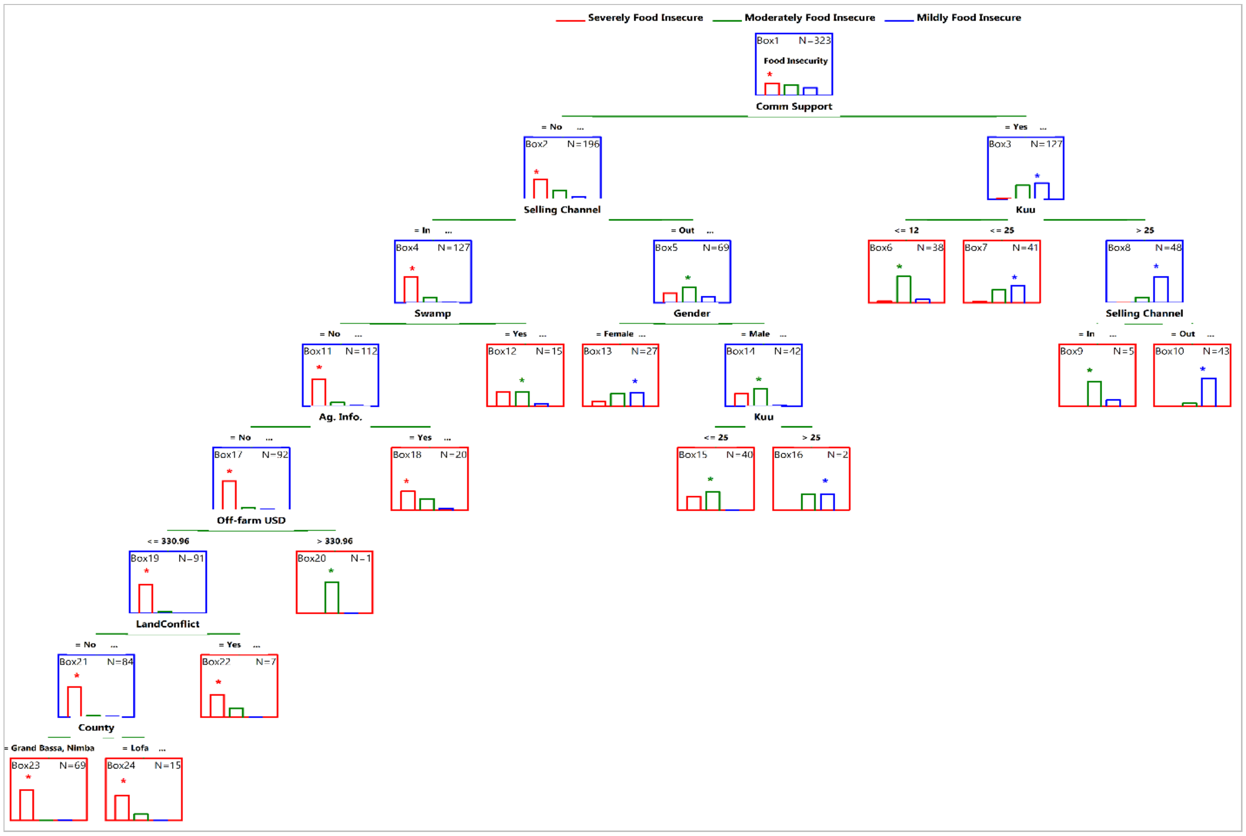
Land conflict indispensably emerged as land becomes more productive. However, amid no proper land rights and failed efforts at in-village mediation, land-related disputes could arise anytime. The seven households (=five severe and two intermediate levels of food insecurity) in Box22 could be vulnerable for protecting inherited or at least where they farm. Leaving the small number of the land-related experiences, most (=80 severely, three moderate-, and one mildly food insecure) seldom had land-related disputes behind infertile land (Box21). The very bottom split predictor asked households' residence. Compared to Lofa residents (=12 severe and three moderate-level families in Box24), many more are Grand Bassa and a few more Nimba residents in severely food insecure (68 against only one in mild-level food insecurity in Box23). Two reasons adhered. One, residents in Grand Bassa and Nimba had smaller off-farm income than Lofa's. But reasonably, most of the 68 in Box23 who were severely food insecure were in Grand Bassa. Too, likely only one in mild was one of the misclassifications in Box 23.

Coming back to the node on the right branch for 127 remnants who took the support of communities, most mildly-food insecure households (=66), more at a moderate level (=57) were in Box3 against four in severely food insecure. Those four severe moved down to a half employ equal, or less than 12 (Box6) and another half retained up to 25 *kuu* members (Box7). Each box had other levels of food-insecurity families (=32 in moderate and four mild in Box6) (=17 in intermediate and 22 in mild in Box7) proportionate to the number of *kuu* members. From 127 in Box3, the higher node size (n=48) went to Box8 rather than Box6 (n=38) and Box7 (n=41). Box8 accommodated farming households that worked with more than 25 *kuu* members. The last split predictor on the right-hand reappeared selling of crops produced was within or outside villages. Like the decision branch on the left hand, those diversifying selling channels in Box10 (four in moderate/intermediate and 39 in mild food insecure) tended to increase the level of food insecurity than others through a single selling channel in Box9 (four in moderate/intermediate and one in mild).

A three-dimensional graph in Figure 2.4 is to present how precisely the exhaustive CHAID categorized food-insecurity households. The places matched between classes (observed-and-predicted severe, moderate, and mild, diagonally the lowest to top) looked accurate, otherwise misclassified. Of all 323 cases, 104 in severe-level, 61 in moderate-level, and 73 in mild-level food-insecurity matches showed 73.7% (=238/323 cases) accuracy. Eighty-five mismatched cases (26.3% inaccuracy) seemed the other six possible combinations. The most significant discrepancy was in predicting moderate-level intra-household food insecurity. In the mid-layer in green for observed-moderate food insecurity, besides 61 matched cases, 32 predicted-mild and 19 predicted-severe were. More in incompatible cases whose observations were severe in red, 19 predicted-moderate six predicted-mild followed. The minimum differences were mild-food insecurity predictions in blue of three predicted severe and six indicated moderate beside the matched 73 cases.

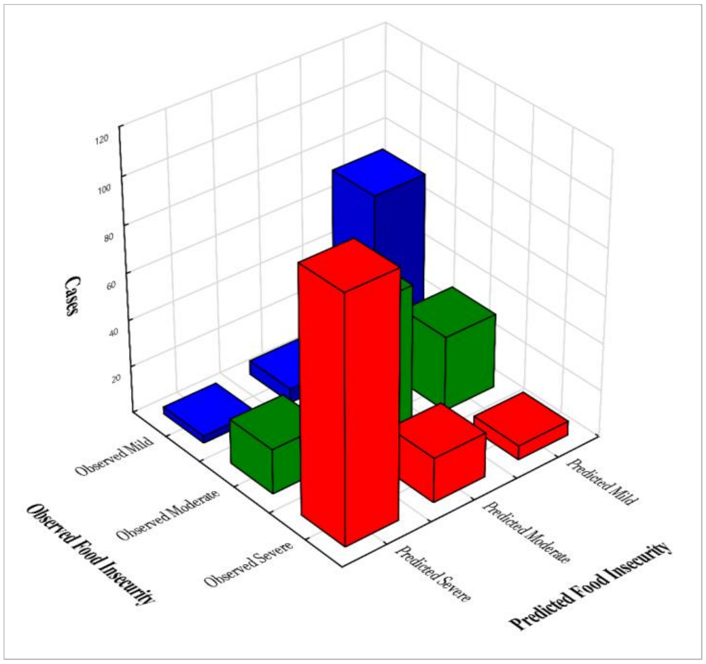
Despite the same small and reliable standard errors (=0.02) for both estimates, v-fold cross-validation delivered a higher mismatched risk (=31.6%) than another from training data (=26.3%). Three plausible explanations are associated. Even with higher error rates than expected, no extreme discrepancy (two levels up or down between observed and predicted cases) was still a valid CHAID result. Those were merely nine extreme mismatched cases, between observed severe and predicted mild (n=6) and observed mild and predicted severe (n=3). Second, more 'found' or 'chosen' split predictors could increase the error rates to classify already different two gender groups. An earlier study included only 112 female-headed households accompanied by fewer predictors and had error rates for misclassification and v-fold cross-validation lower than this study at 14.3% and 27.7% (Ahn et al., 2020). Third, Liberia's smaller cases than the other two countries appealed to more cases and evidence for future studies to reduce misclassification rates.

Figure 2.3 (Liberia) Decision Tree Graph



Note. Asterisk (*) in red, green, or blue atop of a bar signals each node's major food-insecure group.

Figure 2.4 (Liberia) Classification Matrix



Senegal's CHAID algorithm ran two separate times. Gender, *Zakat* (obligatory almsgiving), and *Sadaqah* (donation) were expected to be two powerful predictors for intrahousehold food insecurity. *Zakat* and *Sadaqah* together seemed a mirror of the scale of staple crops for every family.

Resembling Liberia's CHAID result, community support was an explicit predictor of food insecurity levels. Also, the supported (=261) and non-supported (=249) frequencies were almost half each side compatible with information in Table 2.4. Animal consumption to supplement family nutrition seemed equally essential for food security.

Figures 2.5 and 2.6 display two single tree graphs that reflect the above assumptions. The earlier tree took gender (either female-headed or male-headed households) as the first child decision branch from the root node of three food insecurity levels. Of 510 (167 in severely, 230 in moderately, and 113 in mildly food insecure) households, all 114 female-headed families moved onto the left branch (87 in severe, 24 in moderate, and three in mild in Box2). Those continued to face one more question to offer an amount of *Zakat* and *Sadaqah*. Smaller than and equal to 75 kilograms of donated and offered staple crops led 83 severely food-insecure households to Box4. Among the other female-headed families gifted more than the amount, four in severe, 24 in moderate, and the other three were in mild food insecurity in Box5.

On the right branch from the root, 396 male-headed households (the bigger node size) pinned down to food insecurity in Box3 (80 in severe, 206 in moderate/intermediate, and 110 in mild). Leaving as the parent node, eight further splits occurred. Whether credit was equal, less, or more than 80 USD came across two branches. Equal or less than the amount, the CHAID algorithm selected the moderate-level food insecurity as the node's preponderance (=65 in severe, 155 in moderate/intermediate, and 34 in mild in Box6).

Moving down another break, arrived at the USD amount of crop income. Equivalent to and smaller than 824 USD, a majority of 55 in severely food insecure was followed by 35 in moderate/intermediate and only one in mild (Box8). Further to end nodes, an additional question was again the *Zakat* and *Sadaqah* quantity as offering and donation. Same as the previous threshold, 75 kilograms of donated and offered staple crops reappeared for a decision criterion. The ratio of 51:4 in severe between the same or smaller than and more, the larger count proceeded to Box14 accompanied by two moderately food-insecure households. More than the extent was not only four in severely but 33 in moderately and one in mildly food-insecure families in Box15.

To 163 households who earn over 824 USD in Box9, most 120 in moderately food insecure came with 10 in severe and 33 in mild. The number of slaughtered and consumed cattle, sheep, and goat followed to bisect Box9. Equal or fewer than summed total four, 98 families in moderately food insecure followed by 10 in severe and six in mild in Box16. An aggregate of *Zakat* and *Sadaqah* additionally divided the total 114 into two nodes, based on equal, less, or more than 240 kilograms. And the quantity was higher than three times the former benchmark (=75kg). Box18 embraced the households offered up to the newer standard (=10 in severely, 96 in moderately, and only one in mildly food insecure). For over 240 kilograms of *Zakat* and *Sadaqah*, two households in moderate/intermediate and seven mild-level food insecurity are in Box19. The last condition to end the parent node that included 254 families who could not access credit exceeding 80 USD is the diversity of crop selling locations to the 107 households in Box18. On the left (Box20), 76 (=a majority of 66 households in moderately and ten others in severely food insecure) were, but 31 (=a majority of 30 families in moderately and the sole household in mildly food insecure) were on the right (Box21).

Back to the parent branch regarding the credit amount in USD (=$80), the right node contained more than the amount. In Box7, 15 in severely, 51 in moderately, and 76 in mildly food insecure added up to 142 households. Below further bifurcation kept on asking the amount of *Zakat* and *Sadaqah*. Now the quantity (=192kg) was larger than the first standard (=75kg) but smaller than the second basis (=240kg). Equal or smaller than the newest base, 53 (=a majority of 36 families in moderate-level followed by 15 in severe-level and two mild-level food insecure) were in Box10 on the left. On the right hand, whose *Zakat* and *Sadaqah* amount was more than the comparison, Box11 selected mildly food-insecure households as a major category (=74) against 15 at a moderate level. The 89 remainders confronted the final question.

Agricultural technology was an ordinal category, whether the status of basic and intermediate (=0 and 1) or high and advanced (=2 and 3). For the lower-tier technology, 58 farming households were in Box12 (=a majority of 43 in mildly food insecure, followed by 15 at a moderate-level.). The other 31 families who used the higher-tier technology were mildly food insecure only in Box13.

Figure 2.7 is another three-dimensional graph to show the accuracy of first Senegal's decision tree in figure 2.5. Diagonally from the lowest to highest positions, the matched 429 (134 severely insecure; 189 moderate/intermediate; 106 in mild) out of 510 cases evinced 84.1% of classification accuracy. Four disparate spots were to explain the other 15.9% of the misclassification rate. Of the green bars at mid-level, the biggest mismatched cases were 39 between observed-moderate and predicted-mild. On the other side, merely two cases were at odds between observed-moderate and predicted-severe. While no extreme mismatches (observed-severe and predicted-mild, observed-mild, and predicted-severe), the second most significant mismatched cases (n=33) arose between observed-severe and predicted-moderate. On the top layer in blue, seven discordant matches were between observed-mild and predicted-moderate. V-fold cross-validation (=17.5%) stayed like the initial misclassification rate. Both remained the standard error of 0.017 alike. Overall, the tree construction and classification were appropriate, with seven predictors to food-insecurity levels.

With five predictors already found (i.e., animal consumption, crop income in USD, credit in USD, gender, and selling location), new predictors of community support and off-farm revenue in USD reshaped Senegal's decision tree in Figure 2.6. In contrast to the preceding, a newer tree included a predictor *community support* to halve the root node (167 in severely, 230 in moderately, and 113 in mildly food insecure households. On the left branch, deprived of village-wide support, the CHAID algorithm picked up 249 food-insecure households with a selected category of severity (n=148) followed by moderation (n=89) and mildness (n=12) in Box2. In turn, severity, moderation, and mildness composed 88.6%, 38.7%, and 10.6% of the households in the same degree whose communities afforded village-wide support (Box3).

Continuing to non-receivers of community support, the number of livestock slaughtered for family consumption also branched off. Equivalent to or fewer than one animal, 118 households narrowed down 106 in severely and 12 in moderately food-insecure homes in Box4. Going further down to Box16 and Box17 were subject to interpretation while leaving behind the other 131 who consumed over the minimum number of livestock in Box5. Based on a condition whose crop income was equal or less, otherwise more than 693 USD, the earlier state accommodated 85 severely and only two in moderately food-insecure households in Box16. More than the amount, 31 households still had a majority of severely (n=21) against ten moderately food-insecure households (n=10) in Box17. Among 87 families in Box16, the end node was either female-headed households (Box26) or male-headed households (Box27). Disproportionately, more female-headed (n=62) than male-headed households (n=25) were classified as severe food insecurity (all 62 female-headed families in severe food insecurity; 23 male-headed homes in severe and two in moderate food insecurity).

Back to the experience where families consumed more than a domesticated animal, a majority of 77 in moderately attended 42 in severely, and 12 in mildly food-insecure households added up to 131 in Box5. To the same criterion of the previous decision tree, 80 USD of credit broke into two nodes. Equal or smaller than the amount, a majority of 70 in moderately accompanied by 39 in severely and five in mild food-insecure families in Box18. More than the amount, two major groups (seven families per moderate and mild food insecurity) were with three in severe food-insecure households in Box19.

To 114 who could not afford equal or less than the credit amount in Box18, another criterion appeared—the amount of crop income (=1,137 in USD). Over that value, six families halved in moderate and mild food insecurity in Box21. Equivalent to and less than the value, a majority of 67 in moderately together with 39 in severely and two in mildly food insecure households added up to 108 in Box20. The same homes met the earned amount of off-farm income (=200 in USD). More than the amount most (n=23 families) was in moderate food insecurity followed by one in severe and two in mild in Box23. Equal or below in Box22, 82 households were divided by 44 in moderate as a majority and 38 in severe food insecurity levels. The final nodes were dependent on which gender managed farms. Male-headed households tended to have more moderate (n=38 households) and 25 severe food-insecure households in Box25. On the contrary, 19 female-headed families were more involved in severe food insecurity (n=13) than in moderate (n=6) in Box24.

Shifting toward the first branch, the eastside node brought 251 households with community support in Box3. Specifically, a majority of 141 in moderately and 19 severely food-insecure families and another majority (101 of the total 113 in mildly food-insecure households) or 89.4%, were in Box3. The next repeated question became the number of combined cattle, sheep, and goats consumed to enhance food security.

Based on a new standard, equal or fewer than four animals in Box6, or more in Box7. In Box6, 145 households consisted of 116 in moderately, accompanied by 18 severely and 11 mildly food insecure households. By contrast, in Box7, a majority of 90 in mildly, followed by

25 in moderately, and only one in severely food-insecure households were. Both sides faced two different questions to advance more branches and nodes.

Most moderately food-insecure families met a question either up to or more than the amount (=1,033 USD). Over the value, most 81 households in moderate were after 10 in mildly food insecure households in Box9. Equal or less than the value, still a majority was the moderate-level food insecurity (n=35) also with 18 severely and only one mildly food-insecure families in Box8. Major groups differed from Box8, whether female-headed (Box14) or male-headed households (Box15). In Box14, the number of female homes that appeared most often was in severe food insecurity (n=8) and four at a moderate level. Among 42 male-headed families in Box15, a majority was in moderate-level food insecure (n=31), followed by 10 in severe and one in mild.

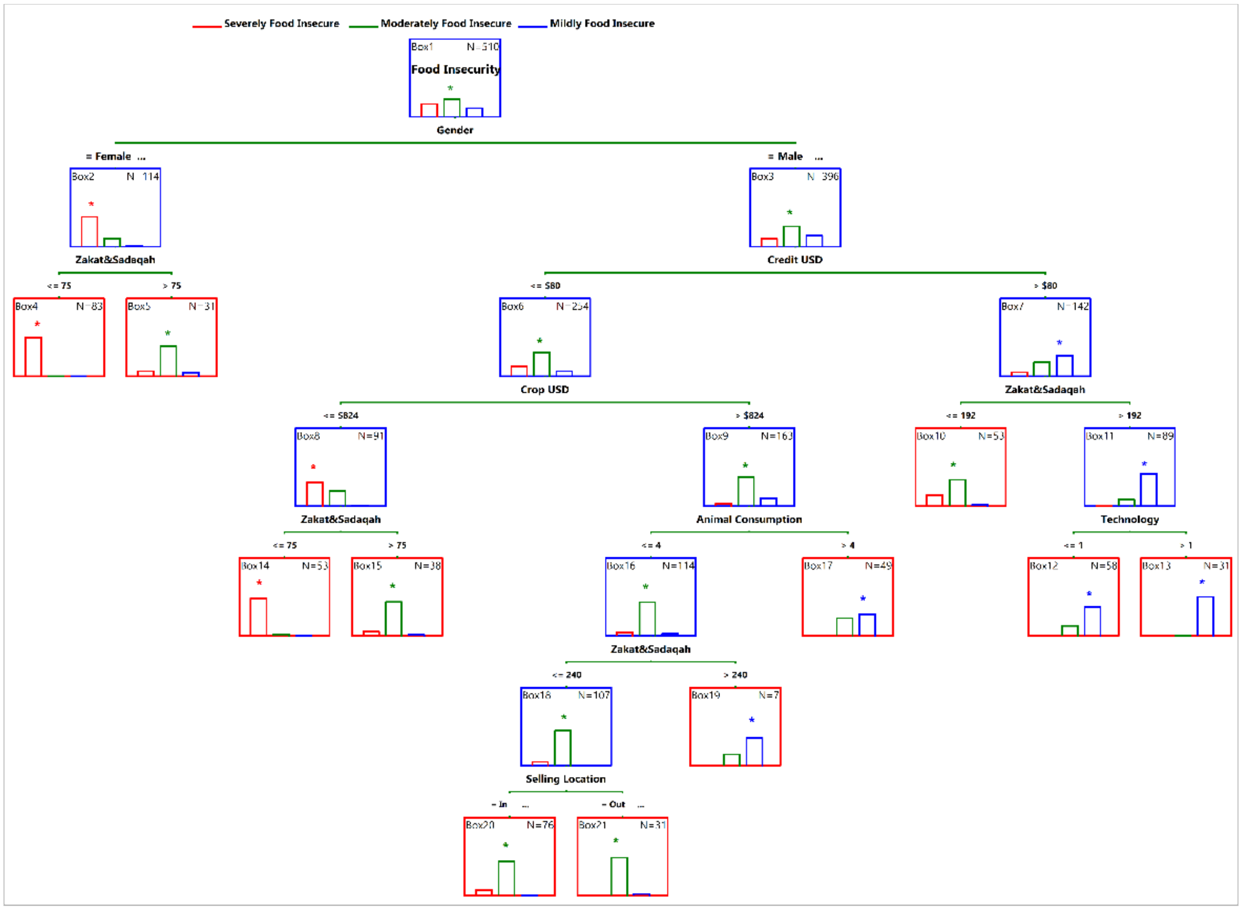
To 116 households for more than four consumed animals, the amount of off-farm income (=200 USD) became a standard to divide into two nodes. More than the value, 60 households broke down in mild as a majority (n=59) and another moderate/intermediate in Box11. Equivalent to and lower than the value, the number of food-insecure families similarly appeared most often in mild (n=31), but also with two other categories in moderate/intermediate (n=24) and severe (n=1). Each side progressed along with another question. Although the off-farm income was equal to or smaller than the amount, 18 households who sold their agricultural produce outside the residence were classified as mild in Box13. Also, with the mode, Box13 accompanied five others at a moderate level. To those neither more than 200 USD of off-farm income nor capabilities of selling their produce outside the village, the number of food insecurity appeared most often changes to a moderate level (n=19), followed by 13 in mild and one in severe.

Figure 2.8 is attached to the accuracy of second Senegal's decision tree structure. The match 406 (127 severely food insecure; 202 moderate/intermediate; 77 in mild) out of 510 observations proved 80% of classification precision on the diagonal cross. In reverse, 20% of the misclassification rate (104 of 510 cases) arose the most considerable discrepancy (n=40 between observed-severe and predicted-moderate) and the next (n=36 between observed-mild and predicted-moderate). The left and right to the middle of 202 matched moderate cases were 22 mismatches between observed-moderate and predicted-severe and six between observed-moderate and predicted-mild. V-fold cross-validation released a higher (=25.2%) misclassification rate than another 20%, with a 0.018 standard error.

Three plausible reasons followed approximately 10% larger misclassification rates than the first Senegal model. First, three different crop-related income standards seemed inflated to dissect branches and led to a higher error rate. Against the amounts in USD, off-farm and credit criteria were consistent in two branches but a minimal difference of each mean (=200 USD and 199 USD for off-farm income; 80 USD and 139 USD credit).

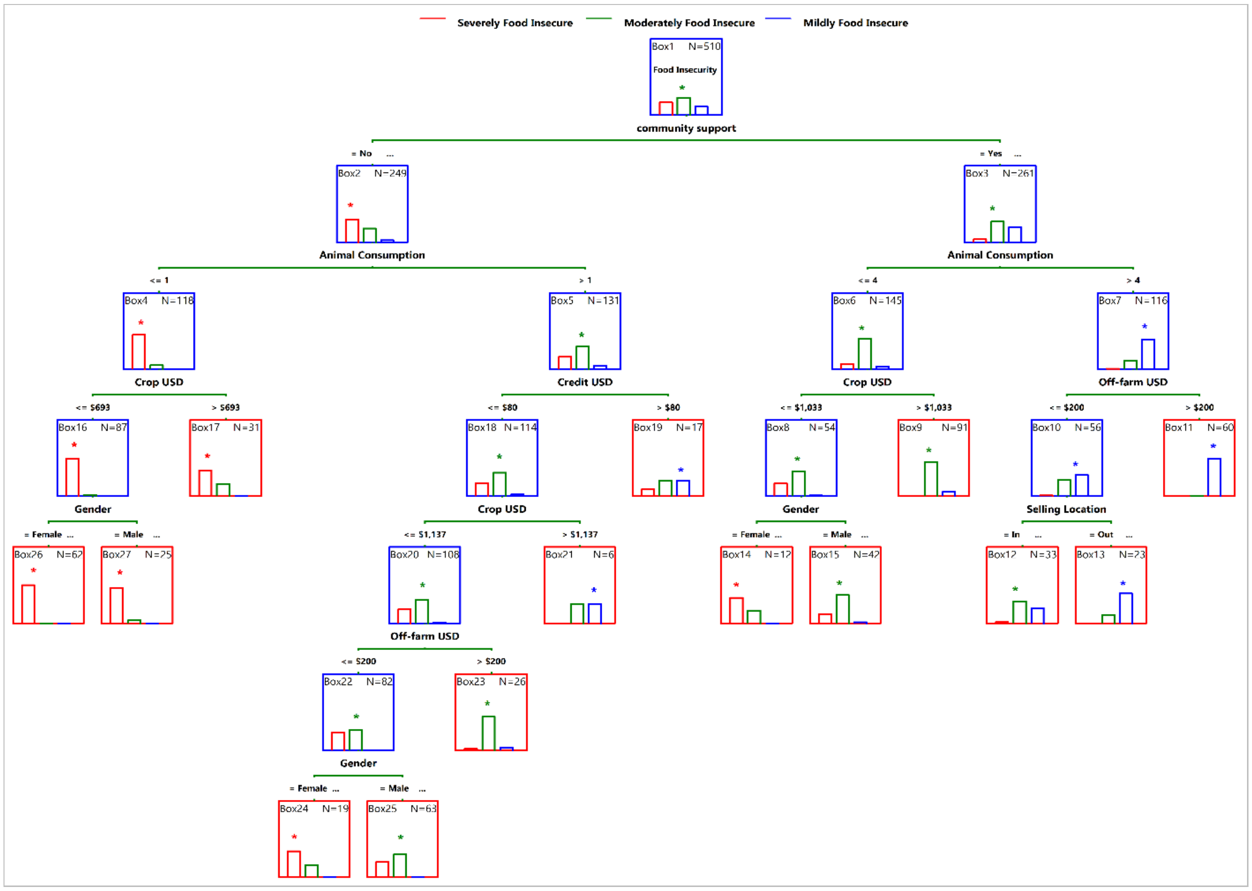
The second reason stayed given financial variations, and more financial predictors caused prediction of the other two levels to moderate-level inaccuracy. All 76 mismatches emerged from both predictions toward the moderate level. Relatedly, the second CHAID algorithm predicted 49 more cases of moderate-level food insecurity than the first CHAID. The third reason remained non-financial predictors of the first tree, especially gender and *Zakat* and *Sadaqah*, to classify three-levels of household food insecurity more precisely than the second tree's financial predictors.

Figure 2.5 (Senegal) First Decision Tree Graph



Note. Asterisk (*) in red, green, or blue atop of a bar signals each node's major food-insecure group.

Figure 2.6 (Senegal) Second Decision Tree Graph



Note. Asterisk (*) in red, green, or blue atop of a bar signals each node's major food-insecure group.

Figure 2.7 (Senegal) First Classification Matrix

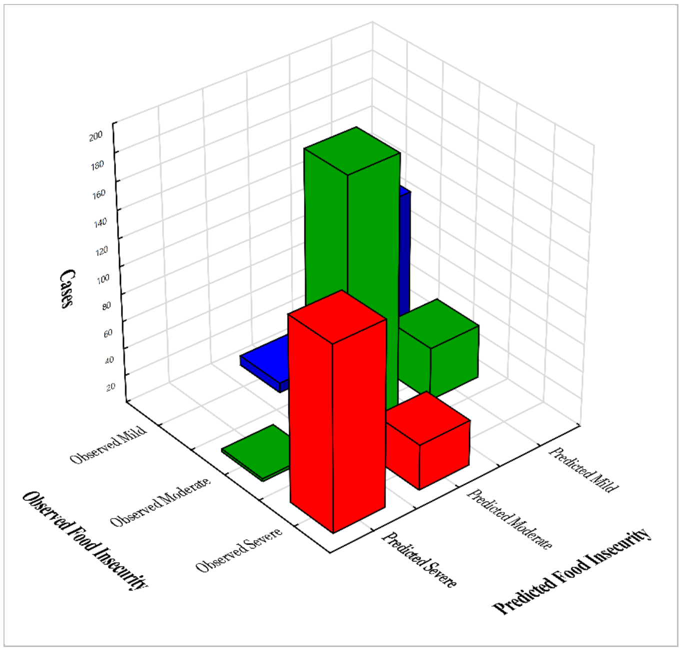
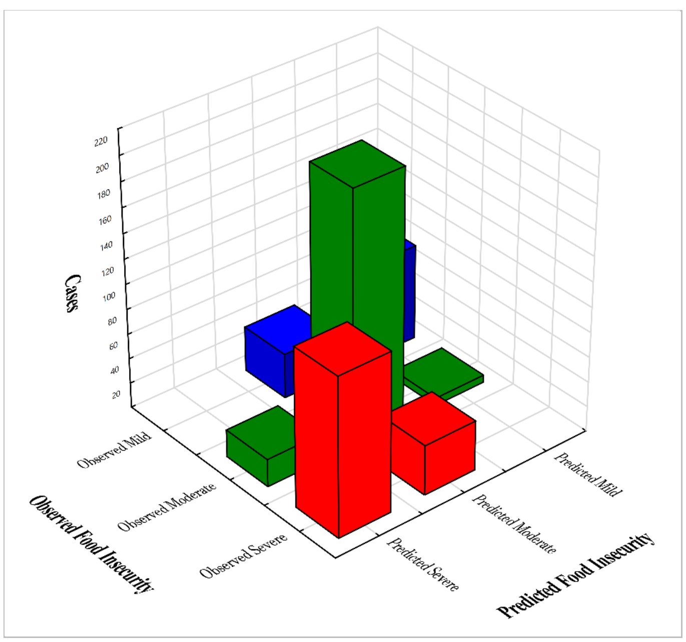


Figure 2.8 (Senegal) Second Classification Matrix



Figures 2.9 through 2.13 are to present the results of Ghana's random forest with three distinctions. Most notably, the machine learning algorithm 644 cases disproportionately for the tree growth (n=222) and misclassification/out-of-bag error rates (n=432) as built 150 individual trees. Compared to the classification of food-insecure households (n=277, 43%) and food-secure households (n=367, 57%) from train (input and original) data, the tree graph as predicted categorized less food insecurity (n=89, 40%) and more food security (n=133, 60%). Out of random subsets, proportions for observed insecure (n=187, 43%) and observed secure households (n=245, 57%) to rate misclassification were identical to train data. Second, the tree graph and misclassification matrix, but the figure of summary, predictor importance plot, and two gains charts for food security, food insecurity referred to interpret the random forest. Third, the ideal scenario recognized that the two classes share an equal proportion, although the application of stability, food availability, and food access seemed impossible to perfectly equal both sides. The risk rate to misclassifications remained low at nine percent in train data.

Ten percent of misclassification rates in new test data that included randomized information also kept minimal training data's erroneous variation (=9%). The low standard errors (0.01 and 0.02 in order) confirmed the ensembled tree graph's construction stable and reliable.

The first characteristic to split the root node was obtainable agriculture-related information. Pieces of information included weather information to prepare for harsh weather, the cost of farm inputs, and up-to-date farm produce prices. Channels varied from market women nationwide, the Agricultural Economics and Agribusiness (AEA), farmer's organizations, and extension agents of the Agric office and Ministry Food and Agriculture (MOFA). One unexpected result was the role of exogenous assistance. Compared between the recipients (n=357) and non-recipients (n=287), external help to train farmers, find buyers, and food aid could be direct, indispensable, and significantly expectedly enhanced food security. The predictor-importance table (Table 2.6) proposed an opposite result that accessibility to agriculture-related information was heavier weight to predict household food security.

Three arguments adhered to the decision:

1. Compared to exogenous assistance, agriculture-related information seemed better to embrace and connect the following predictors to the target variable.
2. The frequencies and scope of exogenous help significantly differed from one district to another. The district as a predictor, the machine-learning algorithm preferred agriculture-related information to bisect the root.
3. Predictor importance was the vis-à-vis relationship between a predictor and the target variable.

A reliable and stable tree construction from the random forest harmonized among the most to least significant predictors. In turn, reliance came how and what predictor advances and complements to the next, instead of too much dependence on only high-ranked or low-ranked predictors to acquire a non-biased tree. Equally important, avoiding correlation between predictors aimed at the same desired result. Consequently, nine out of nineteen predictors were to classify the dichotomous target variable.

One hundred thirty-three in food-secure and 89 in food-insecure cases in Box1 relocated whether accessed to agriculture-related information (n=165) or non-accessed (n=57). Undeniably, a bigger proportion (=117 of 133, 85.7%) among food-secure cases became most of the accessed group in Box2. Among the 89 in food insecure from the root, 41 could not access agriculture-related information relocate as a majority in Box3. With the other 16 cases in food secure, Box3 stretched across four more nodes on the right hand. Notice the tree shapes between

CHAID and Random Forest looked reversed from the most severe food insecurity (left) to the mild (right), but here food security (left) to food insecurity (right).

Another question/branch across the 57 non-accessed was whether the selling channel was diverse or existed in and near the residence. Among 38 cases with limited selling channels in Box23, the most frequent appearance hovered at the food insecurity (n=33) against five in food security. Negative answers on the precedent and diversity of selling channels were crucial distinctions whether a farmer was a price maker or a taker. For instance, according to qualitative information, market women's role varied from agriculture-related informants to the middlemen between farmers and wholesalers/merchants. If the price was known and transparent, minimal effort to negotiate prices between the two sides was necessary. But chances were no informant around to provide such information; farmers would accept a price in the narrowest margin whatever market women, villagers, or neighbors offered. A comparison was possible between farmers who were likely price makers in the trader's position and the others who shared experience in accepting price as harvest perished. The vulnerable position endured other cases where the buyers asked for more in the crop bag than the negotiated amount (over-bagging) or purchased in credit, instead of cash transactions.

In Box22, 19 cases were in another situation where the selling channel was beyond in and near the community. Compared to Box23, a majority seemed to change to food security (n=11) from food insecurity (n=8). Another follow-up question was whether a household satisfied a certain amount of expenditure (=129 USD) on food items to appreciate food security, regardless of family size and districts. Equal or smaller than the value, all seven cases of eight in food insecurity in the precedent moved to Box24. Adjacent to Box24, Box25 took the last leftover case in food insecurity with most food-secure instances of more than the value.

To the node where 165 positive cases accessible agriculture-related information in Box2, most were now food-secure cases (n=117) against food-insecure instances (n=48). The next long branch waited for the condition of resident districts. Because, unlike the others, residents in the Northern region reported different, more evolutionary-like farming practices. Willingly and primarily, farmers in the area relied on family labor. The amount of tractor, fertilizer, herbicide/insecticide use is small and inadequately comparable with other regions. Many circulated the advent of such services in the field, and 36.3% (61 of 168 households) expected to not only improve their low soil fertility but manage their farms efficiently. A remark that the highest perception of low soil quality was unclear due to erosion, climate change, or less and smaller use of chemical substances. Also, by introducing tractor services in the area, the effectiveness of those services compared with animal power, whose 78% (133 of 168 households) utilized left for the future study.

Given the difference, 46 cases of the Northern region shifted to the direction other districts did not take. In Box5, most stood on food insecurity (n=27) against 19 instances in food security. Box5 again broke into two nodes to the amount spent on food security (=100 USD). Equal or smaller in Box20, frequent observations stayed in severe food insecurity (n=25) countered to seven food-secure cases. Over the amount in Box21, a majority turned reversed, 12 in secure versus two in insecure.

One hundred nineteen (Box4) in Atwima-Nwabiagya, Ejura-Sekyedumase, and Ga West districts on the left separately developed seven additional branches to complete the ensembled decision tree. A majority was disproportionate food-secure cases (n=98) to food-insecure (n=21). Additional disproportion ensued after a branch in which the existence or experience of flood or drought split the node. In three districts, 40.5% (193 of 476 households) had. The machine-learning algorithm brought a similar proportion (37.8%, 45 of 119 cases) into Box7, characterized by drought or flood. Here, most were still food-insecure cases (n=29) despite 76% (16 of 21 cases) narrowed down from the preceding food-insecure cases. More outside laborers (n=9) to alleviate crop failure emerged to those cropped up flood or drought. Equivalent to or fewer than the number, the excessive appearance was food-insecure cases (n=10) against secure cases (n=3) in Box14. In Box15, a majority switched to food-secure cases (n=26) contrary to food-insecure (n=6).

The tree further developed into the crop income in three districts. To 36 cases in Box15, lower, equal, or higher than the criterion (=791.92 in USD) split Box16 and Box17. Equal or lower, the end node divided into a majority in food insecurity (n=4) and a case of food security in Box16. Above the amount, the adjacent node (Box17) had a disproportionate number of food-secure cases (n=25) as a majority against two food insecurity instances. Because only two food-insecure examples lasted, neither node (Box18 nor Box19) changed food-secure cases. To bisect a follow-up criterion was whether the fertilizer use was equal or less, or more than the financial value (=62.19 in USD). The same or smaller, the remainder two food-insecure cases moved toward Box18 with four food-secure instances. Higher than the amount, all (n=21) in food security remained in Box19.

Moving back to the normal circumstance where drought or flood happened, most food security of the preceding Box4 (70.4%, 69 of 98 cases) advanced to Box6 with five food-insecure examples. Progressing a branch to determine more decisions was the number of outside laborers bifurcated Box8 and Box9. Equal or fewer than a benchmark (=7) in Box8, most stayed nine in food security against two in food insecurity. Above a standard in Box9, the frequency was disproportionate food-secure (n=60) to only three food-insecure cases.

Herbicide/Insecticide use positively correlated with fertilizer, and both predicted balanced in different positions to food insecurity/security. To 63 cases that incorporate more than seven workers under the minimum effect of sandstorm, drought, or flood, another advanced decision standard was to spend the aggregate financial amount of herbicide/insecticide (=157 USD). This benchmark exceeded the mean (=100 USD) and median (=50 USD); those two calculations excluded the Northern region. Over the value, all 28 cases were in Box11. Equal or below the amount, most prevailed in food-secure (n=32) alongside three food-insecure cases in Box10. One further branch to end Box10 was if 35 cases had equal, less, or more than the number of family laborers (=3). Equal or fewer than the number, the whole number, or inconsequential three cases in food insecurity and food-secure cases (n=11) added up to 14 instances in Box12. Next, all 21 food-secure occasions in Box13 involved more than three family laborers.

Table 2.6 and Figure 2.10 are distinctive outputs of random forest that expound on various predictor levels of importance to food security. Financial information was seven pieces showing household income, cost, and credit. Crop income was ranked on top among 19 predictors, followed by off-farm as the 7th and animal income as the 14th in importance. Cost information located after crop income but paired the second-tier priority. Individually, the amount spent on fertilizer and herbicide/insecticide ranked the 2nd and 4th of the biggest predictability. In another category, predictor *money spent on food items* whose role directly to obtain, balance, and enhance household food security reached after crop income and fertilizer use.

The machine-learning algorithm excluded credit in the ensembled decision tree also put that in the lowest importance among financial predictors. Arguably, the median value of credit

(=0 USD) and mean (=60 USD) in Ghana were lower than Liberia's median (=28 USD) and mean (=65 USD). Despite the same median of zero, Ghana's mean was 78.46 USD lower than Senegal's. Atwima-Nwabiagya showed the third quintile (=160 in USD) and a maximum of 398.85 USD. The other communities merely displayed outliers beyond the boxplot. In proper sequence, Ghanaian farmers tended to rely more on income, less credit.

Exogenous or *external assistance* was expected to predict food security robust in the tree and rank higher importance, as more (n=357) households receive such than non-received (n=287). Consequentially, the results proved this and credit not necessarily causing autonomous household food security.

Neither gender-headed households nor land conflict was in the tree. Reasonably, this stemmed from disproportionately a smaller number of female-headed families and those experienced in land-related disputes. The difference from both predictors made it insignificant to the target, as do others.

Nearly all count and binary predictors were in the middle of importance. Constraints of farming and feeding household members got relatively more attention (=5th and 9th) to predict food security, but neither was in the tree formation. Farming technology seemed the opposite direction to elevate food production but merely is in the eighth position of importance. Outside in the sixth and family labor in the 15th as human capital stood separate but complementary to explain parent nodes (drought/flood; district; agriculture-related information). Together predicted, the more laborers were, the higher the food security was.

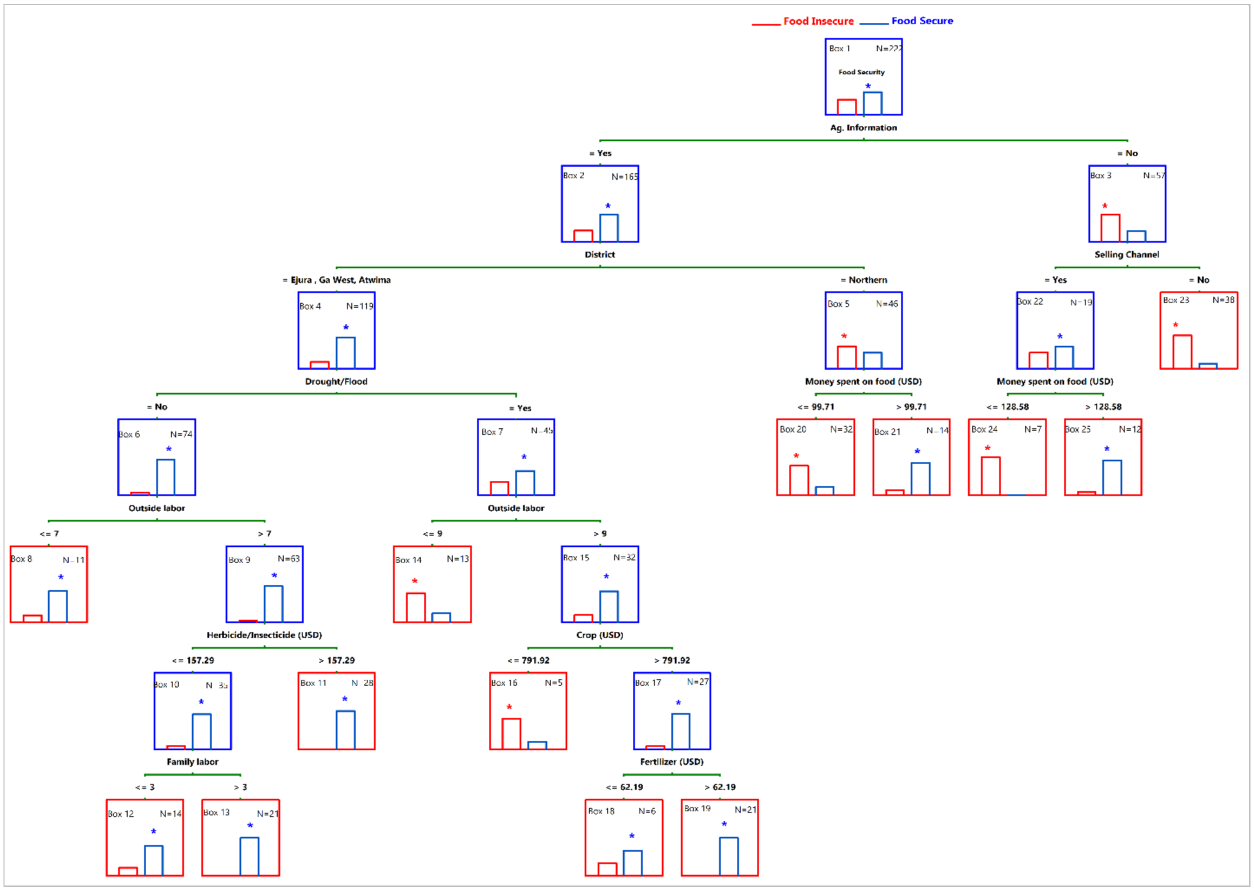
The selling channel (13th) came immediately after agriculture-related information (11th) and drought/flood (12th), and all predicted significantly in the tree as child and parent nodes. A chain reaction whose an answer to such information led to a diversity of selling channels on one side and drought/flood on the other side came out.

District in the tenth predictor that emerged. As a nominal category, residence information advanced more branches and nodes to yield meaningful and realistic results.

Table 2.6 Predictor Importance to Food Security

Predictor	Rank	Importance Statistic (Score)
Crop income (US$)	1	1.000 (100)
Fertilizer (US$)	2	0.825 (83)
Money spent on food (US$)	3	0.804 (80)
Herbicide/Insecticide (US$)	4	0.586 (59)
Constraints	5	0.573 (57)
Outside labor	6	0.492 (49)
Off-farm income (US$)	7	0.481 (48)
Technology	8	0.435 (44)
Feeding household members	9	0.429 (43)
District	10	0.404 (40)
Agriculture-related information	11	0.325 (33)
Drought/Flood	12	0.324 (32)
Selling channel	13	0.323 (32)
Animal income (US$)	14	0.304 (30)
Family labor	15	0.293 (29)
Credit (US$)	16	0.229 (23)
Exogenous assistance	17	0.194 (19)
Gender	18	0.149 (15)
Land-related conflict	19	0.129 (13)

Figure 2.9 (Ghana) Random Forest Graph



Note. Asterisk (*) in red or blue atop of a bar signals each node's major food-insecure group.

Figure 2.10 (Ghana) Importance Predictor Plot

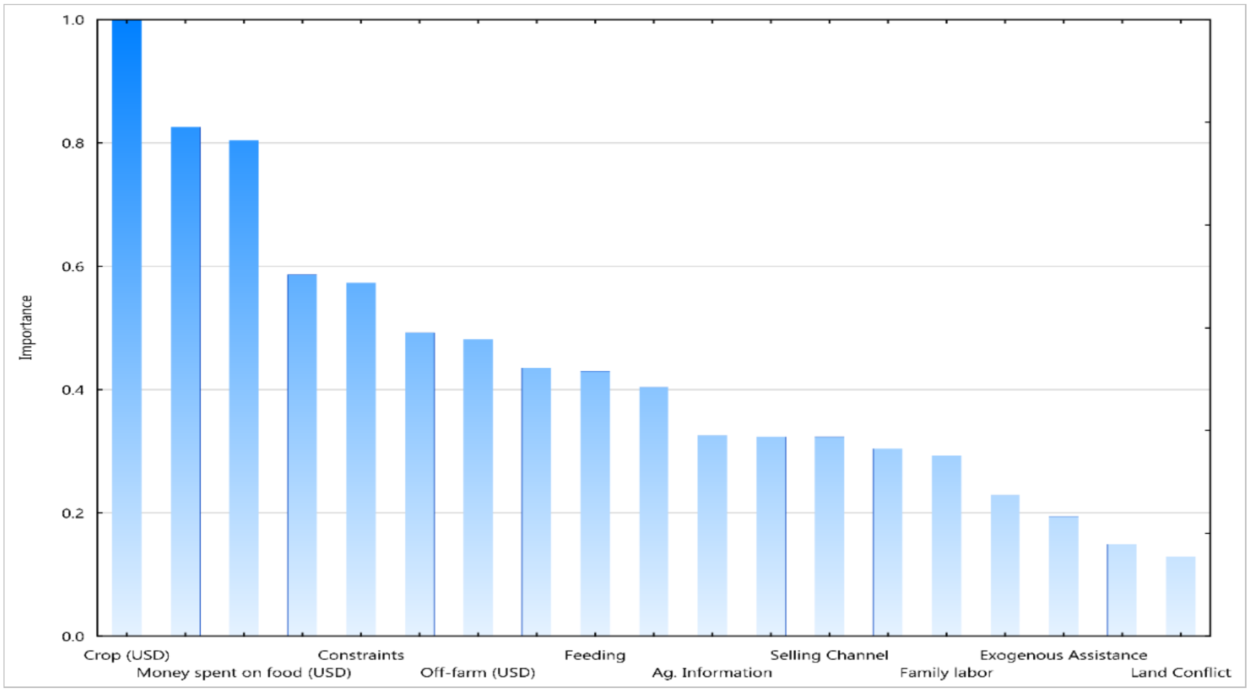
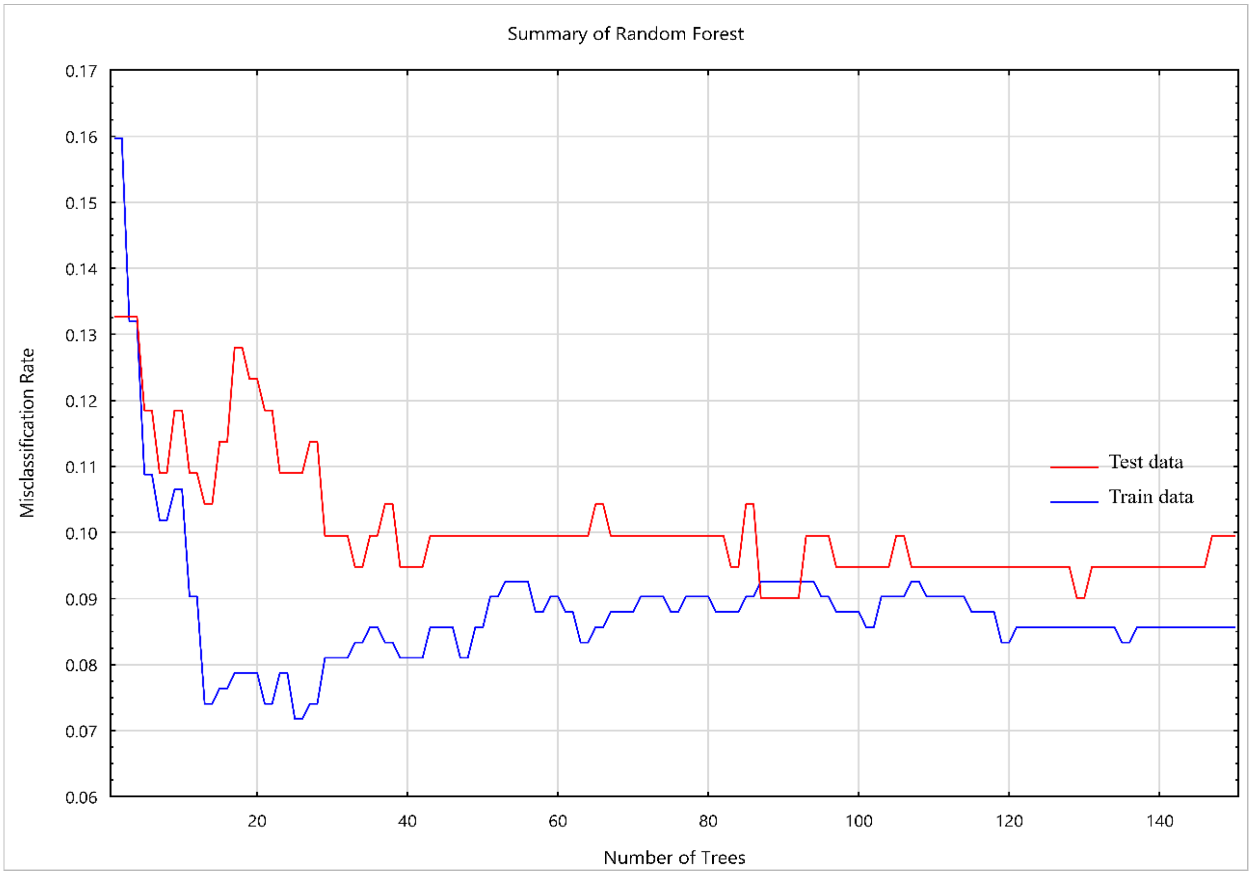


Figure 2.11 is to resume how misclassification rates of the train and test data moved up and down and met to a point, as individual trees built chronologically. Starting rates between the train and test data differed one (=16%) another (=13.2%). Between 10 and 20 trees formed, both erroneous rates turned in a reverse direction. Unexpectedly, the misclassification rate of test data suddenly soared as opposed to going lower for train data. Afterward, the divergence went narrower and overran near nine percent of the misclassification rate on 90 trees. Despite the slight movement to 150 trees, both kept under ten percent of the erroneous estimate.

Overall, the final mismatches error between new test data and train data maintained low enough (below ten percent) alongside the dependable standard errors of 0.01 and 0.02.

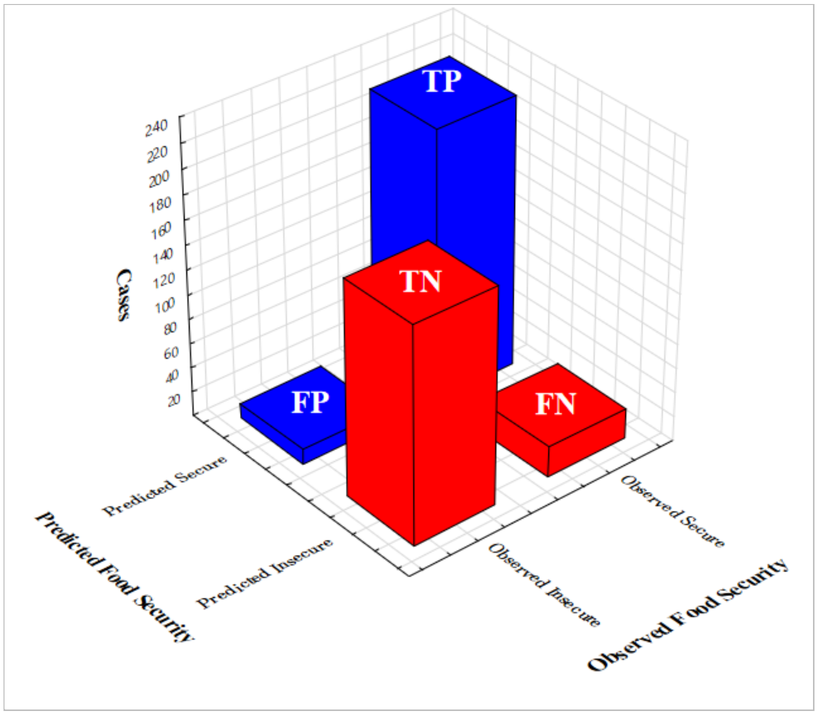
Figure 2.11 (Ghana) Changes of Misclassification Rate as Trees Built



Note. Train data are original, a one before modeling. Test data are other subsets with randomly selected for model-accuracy testing.

Ghana's three-dimensional classification matrix looked simpler in binary information to the previous three matrix graphs (Figure 2.12). Diagonally downward to upward or labeled TN to TP, 175 and 220 precise matches were against 12 of TP and 25 of FN mismatches on the opposite diagonal. Together, 395 correct and 37 incorrect cases left 91.4% accurate (395 of 432) and 8.6% inaccurate classifications (37 of 432).

Figure 2.12 (Ghana) Classification Matrix

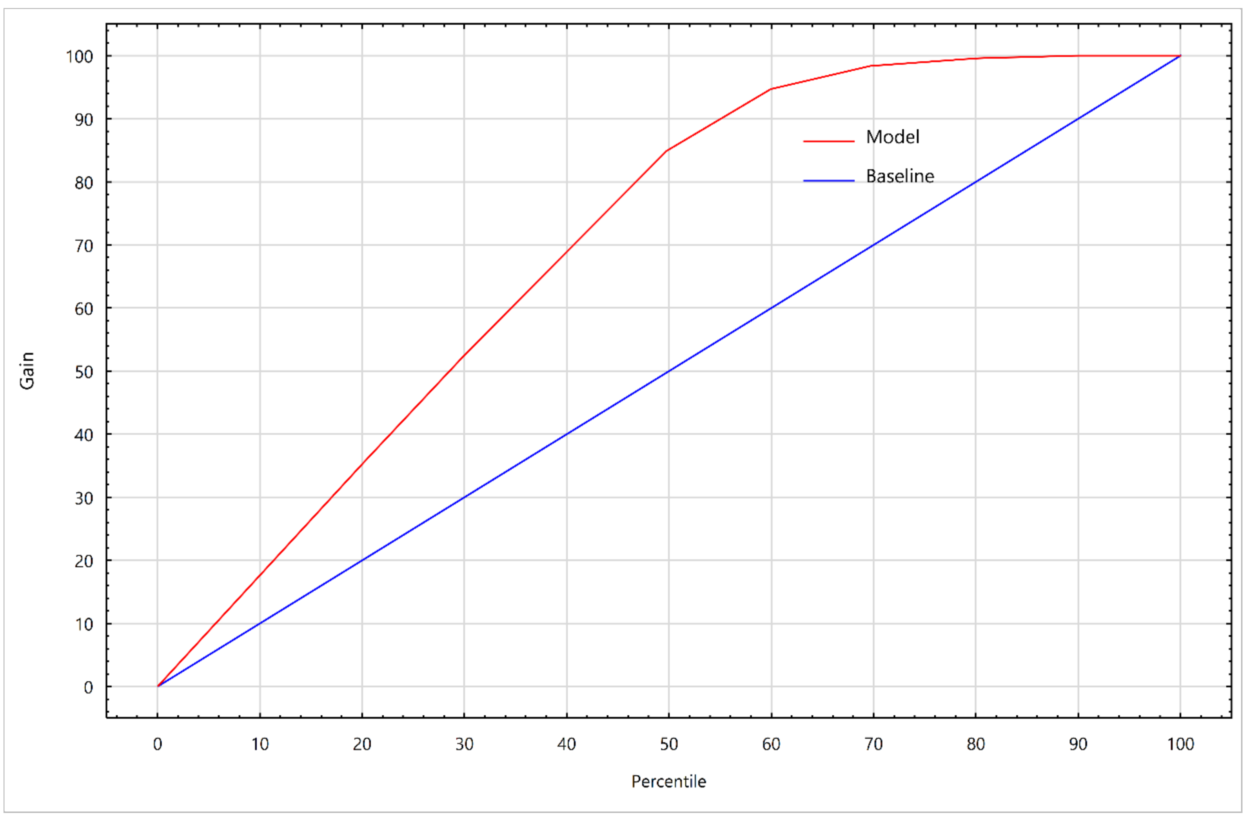


Figures 2.13 is a cumulative gains chart that targeted positive or food-secure responses. The analysis mainly reported a probability of food-secure or positive cases for the study's completion and accuracy. Against the x-axis showing the baseline percentage, the y-axis responds to the proportion within the target range.

Above the 45-degree baseline, an evaluation was possible. The baseline represented random observations with no definite selection criteria. The relationship between the target on the x-axis and the positive response on the y-axis was proportionally one-to-one. For example, targeting 15%, 20%, or 50% would gather the same positive rate of 15, 20%, or 50%.

Among 644 households, the first 10% of the target found 18% of positive responses or about 116 food-secure families, compared to 10% of positive rate or 64 households in food security. The growth rate became quickly higher than the baseline. Merely 30% of the target would yield above 50% of positive responses or 328 food-secure households. Moving forward, 50% of the destination on the x-axis could capture 84% or 541 food-secure families. After 70% of the target took 98% or 631 food-secure households, the growth rate became visually flat and nearly zero. Coherently, the classification matrix and gains chart implied more food-secure homes than others not.

Figure 2.13 (Ghana) Gains Chart for Food Security



2.11 Implications and Recommendations

The decision-tree analysis helped organize scattered survey predictors under the notion of food security. The tree-shaped results, interpretations, and misclassification rates propose how, when, and what agricultural leaders should learn from farming dynamics to reduce food-insecure households. A one-size-fits-all approach that supports the same education, extension, or exogenous assistance with no clear understanding of the country, district, and community will only result in short-sightedness. Despite information from the same questionnaire, the machine-learning algorithm chose different predictors to explain food insecurity and the binary of food security.

The results provide evidence that claims community support to food-insecure households must be foremost in Liberia and Senegal. Kinds of support include a concerted effort to mitigate food insecurity, train farmers in enhancing food production, explore diversified selling channels, and build bargaining power for agricultural competitiveness. The community must also promote egalitarian decision-making, whether the farmer is male or female, advantageous or vulnerable. When land conflict happens, for instance, the voice must be equal. Farming and household decisions for food security also remain equal. Here, individual farming households represent and resemble the wellness of each community and vice versa. The community and its members are responsible and destined for prosperity and property development.

Zakat and *Sadaqah* were a common powerful predictor of Senegal's food security. The amount reflected the production of individual households' staple crops (and toward produce capabilities and food-security status) and essential for almsgiving and stabilizing each community. Highly recommended, agricultural educators, extensionists, and community leaders trace *Zakat* and *Sadaqah* over time to determine individual households' and collective food security.

Ghanaian farmers showed advanced levels of farming practice and food security. Extensionists, educators, and other stakeholders should provide accurate agriculture-related information to farming households to pursue adaptive farming in climate change and apply ideal farming inputs, laborers, and technologies. And more agribusiness strategies should be to set demand and supply of farm outputs for commercial agriculture.

One unexpected predictor to influence food security was the number of family laborers. As independent decision-makers on farming, household decisions for food security, and complementary outside labor, family labor's role seems imperative.

Almost all districts, counties, and regions showed a similar level of agricultural development. (Ex-ante) The in-depth understanding between extension educators and individual farmers must occur before the placement of tailored assistance.

2.12 Conclusions and Discussions

Agricultural production is a unique attribute for individual households and those members' communities. They face challenges and constraints in rainy and dry seasons from land preparation, harvest, and planning for the next cropping season. If a household has obstacles within a cycle, extension educators keep noted qualitatively and indicate the specific situation. If those persist with the family and others in a community, the quantitative proof and explanations should be. Community-to-community comparisons should be afterward. The whole process is the realm of social science.

Commonplace, albeit at different levels, female farmers recorded lower household income but more constraints. To compare both genders in equity, extension education and additional agricultural services should be in a timely and made-to-measure fashion.

Between ex-ante field evaluations and ex-post tailored extension education, evaluations should be iterative and continue to learn the farming dynamics.

CHAPTER III

RADIO COMMUNICATIONS ON FAMILY PLANNING

3.1 Introduction

Family planning includes all possible methods of protecting a woman from pregnancy and a couple's practices between birth intervals to determine the number of children. It is not merely a woman's giving fewer births but embraces a couple's decision making on the ideal family size based on situations, environments, conditions, and other factors under consideration. Reasonably, family planning consists of knowledge and (contraception) use domains.

Family planning is a national strategy. A recent national emergency declared by Liberian President George Weah on preventing women from rising sexual offenders shows particular attention in West Africa (Al Jazeera, 2020). Every woman deserves to be free from sexual assaults and intimate partner violence (Doyal & Gough, 1991).

The Population Division of the United Nations (2020) delivered a concern of unmet, unwanted, and unexpected childbearing among sub-Saharan female adolescents. In a decade, despite a projection of a 60% increase in modern contraceptive use in the south of the Sahara, more than 50% of the world's teenagers with unmet needs will be in sub-Saharan Africa. Anticipation continues for more unplanned births in rural due to a significant knowledge and contraceptive gap between rural and urban areas. Maritz and Probyn (2017) reported a common trend of the middle class in Accra and nine other megacities in Africa of keeping smaller family size for economic affordability. On another occasion, field visits and observations list aging and youth urbanization as two social and communal challenges among villagers/farmers (Ahn, 2017).

Family labor as human capital is essential to sustain rural communities from man/woman power supply for agricultural production and make various farm produce decisions to sell, consume, and support one another.

The populations of Ghana, Senegal, and Liberia persist in 13th, 23rd, and 37th places among 58 nations in Africa; with no significant increase in staple crop yield by 2050, involuntary and voluntary birth control may be the second-best policy to prevent widespread food insecurity among its people (Worldometer, 2020).

3.2 Objective and Research Questions

The primary objective was to evaluate the effectiveness of family-planning information via radio communications on attitude toward family planning. The analysis unit (target population) was 15-49-year-old women in Ghana, Liberia, and Senegal who were pregnant, fecund, and lived with husbands or partners. Structured research questions below:

1. What is the effect of family-planning information sent and received by radio on the perception of the ideal number of children?
2. How can the actual use of contraception impact the family planning paradigm?
3. How would the loss of children affect their perceptions of the ideal number of children to birth?
4. How do partners'/husbands' decisions influence the ideal number of children?

Radio communications, as a medium of family planning information, was the primary treatment.

3.3 Data and Unit of Analysis

We aggregated Ghana (2008, 2014), Liberia (2007, 2013), and Senegal (2010-2011, 2016, or 2018) Demographic and Health Surveys (DHS) to panel data. Created separately, 2018 Senegal DHS was in another panel data to compare the 2016's results (We marked (1) for the result figures with Senegal 2016 and (2) with Senegal 2018.). Each comma identified and divided time zero (pre-treatment) and one (post-treatment). All were DHS's individual recode of women, aged 15 to 49 years, continuous surveys conducted over multiple phases and consecutive years, and incorporated essential socio-demographic, family planning, gender, fertility, morbidity, and other health-related information (Corsi et al., 2012).

Some DHS questionnaires load specific questions. For instance, in 2013, Liberia DHS asked the female respondents to hear, watch, or receive information on the nationwide family-planning slogan, *Baby by Choice, Not by Chance*. In support of Liberia and the Maternal and Child Health Integrated Program of the United States Agency for International Development (USAID), the country observed a contraceptive day. Liberian women learned and accessed modern contraceptive methods (condoms, pills, shots, or birth control implements). Educational posters, advertised *Family Planning is Good for Baby Ma*, were also attached to villages and hospitals (Stadnicar, 2013). After survey-weighted, 7538 (=28%) respondents not recognized, 19,007 (=71%) marked 'received' the information or 'heard' the slogan (120 answered do not know or skipped the question.). Proportionately, 18,403 of the 26,665 (=69%) who received the information agreed that they received it from radios. Divided by place of residence, urbanites (10,739 of 13,211, 82%) heard the information—a larger percentage than among their rural sisters (7664 of 13,454 rural respondents, 57%). Also, in 2008, Ghana DHS included three questions pertaining to family planning needs with yes/no response choices: Having too many children (1) *was dangerous for women*, (2) *better not to have more children than can be afforded*, and (3*) children from smaller families are more likely to succeed*. The responses were similar in urban and rural areas. Eighty-four percent (1016/1216 urbanites) and 79% (1315/1660 villagers) agreed (answered “yes”) on the statement (1). For (2), 94% (1138/1216 urbanites), and 91% (1503/1660 villagers) answered affirmatively. Finally, 85% (1028/1216 urbanites) and 81% (1347/1660 villagers) agreed with the statement *children from smaller families are more likely to succeed.* This DHS information implies urban and rural females’ preference for family planning.

Change of perception and understanding empowered the study. Based in 2008 Ghana DHS, 946 female respondents (33%) agreed contraception is only a woman’s business or her concern versus 1809 naysayers (63%) (122 or 4% had no clue or skipped the question.). Compared to further urban versus rural, more rural sisters (571 of 1660 or 34%) than urban ones (374 of 1216 or 31%) agreed with the statement; Contraception is a primary responsibility of women.

We considered 22,608 individuals (18,117 married, 4491 living with partners; 18,473 fecund, 4135 pregnant) in 2008 and 2014 Ghana DHS, 2007 and 2013 Liberia DHS, and 2010-11 and 2016 Senegal DHS. Another aggregated data set of 2018 Senegal DHS yielded slightly more individuals: 22,699 (18,217 married, 4482 living with partners).

The proportion of radio listeners (n=10,351, 46%) on family-planning information was, albeit smaller than non-listeners (n=12,256, 54%), sufficient to compare treatment effect on perception change (knowledge domain) in 2008 and 2014 Ghana DHS, 2007 and 2013 Liberia DHS, and 2010-11 and 2016 Senegal DHS. With 2018 Senegal DHS, more listeners (n=10,729) were, and the proportion was 47% versus non-listeners 53% (n=11,969). The almost equal division between received and non-received and more radio listeners helped us proceed with the ex post facto treatment study.

Asiedu (2012) examined the importance of radio communications in SSA. Despite radio being the oldest medium among the possible information communication technologies (ICTs), most rural women in SSA rely on radios as a primary information source. Local radio stations communicate and are familiar with native knowledge. Regional dialects and indigenous cultures seem a more effective oral medium than others among homemakers, female farmers, and others working outside houses. Based on every point, Asiedu (2012) recommended a bottom-up approach that radio coupling with another ICT in SSA. This literature consistently tells radio communications are non-discriminative and reach out more than other ICTs in SSA.

Notice we accepted listeners who accessed other communication channels from evaluating the radio's effectiveness for external validity (generalizability). When we limited radio communications as the sole messenger, the received number decreased significantly from 10,351 to 1157 (with 2016 Senegal DHS) and from 10,729 to 1172 (with 2018 Senegal DHS). We did not consider the received number of Television (n=5539), Newspaper (n=919), at health facilities (n=6634), or from Family-planning workers (n=2694) as significant treatment channels. With the 2018 Senegal DHS, the received number had a slight change, Television (n=5776), Newspaper (n=1003), at health facilities (n=6689), or from Family-planning workers (n=2338). However, we accepted cases of multiple exposures to family-planning information channels if respondents listened to radios for a family planning channel.

3.4 DHS Literature

Existing DHS literature on family planning informed the study. Most relevant, Kim et al. (2019) analyzed the 2014 Senegal DHS and found audio-visual communications and audio-visual-based literacy education via radio and television enhanced Senegalese women's family planning.

Sougou et al. (2020) had another year (2017) of the Senegal DHS to lower unmet needs by women's autonomous decision-making power of their health. They applied propensity score matching based on autonomy as a treatment to split the data into two groups (control and treatment groups). Their research was quite unanticipated. Only 6.26% of women had autonomy in their health, while 80.33% relied on partners'/husbands' decisions concerning their health.

Senegal's DHS was with other countries' DHS for further analysis. Malarcher and Polis (2014) included Senegal, Uganda in Africa, and Nepal in Asia to provide a map of where most women needed contraception and family planning. Spatially, family-planning services vary significantly, and the recommendation was to provide a unified and consistent service to meet needs. Leslie et al. (2017) covered more countries in Africa (Senegal, Kenya, Malawi, Namibia, Tanzania, Uganda, Rwanda) and Haiti. On average, they found integrated health coverage of antenatal care, family planning, and childcare was lower than 30%. And we found the essence of the quantity and quality of health services.

Chakraborty and Sprockett (2018) studied family planning across Ghana, Liberia, Senegal, five other African countries, two in Asia, and another two Caribbean countries. Among a dozen countries, modern contraceptive use varied from approximately eight percent to 53%. Unlike Ghana, Liberia, Senegal, Mali, and Zambia, wealthier women in Kenya, Nigeria, the Democratic Republic of the Congo, and other continents' countries relied on private family-planning services. In an earlier study, Hutchinson et al. (2011) compared the quality of private and public family-planning services with Ghana, Kenya, and Tanzania in sub-Saharan Africa. As more highly incentivized service providers, private services were rated higher. Users gave higher satisfaction scores for efficient treatment, vis-à-vis interpersonal communications, and shorter waiting times. The primary recommendation was to incentivize public-sector providers for equitable and competitive family-planning services toward the most dependable pregnant and reproductive-age women. Agha and Do (2008), whose family-planning study in Ghana and Kenya, urged more active public-sector intervention to increase modern contraception use among the poorest rural women.

Amoako Johnson and Madise (2009), focused primarily on the 1998 and 2003 Ghana DHS, found that unmet needs varied significantly from one area to another. Those behaviors were similar overall for neighboring rural villagers but dissimilar for urban couples. From the 2014 Ghana DHS, Seidu et al. (2019) identified those who used contraception were more educated and had more visual exposure (watching televisions minimum once per week). Atiglo and Codjoe (2018) analyzed the same data to relate women's autonomy on household decisions to contraception and found age, education, wealth, type of residence (rural or urban) differentiate contraceptive behavior.

Butame (2018) featured 3373 15-59 male respondents in 2014 Ghana DHS and realized education, age, and those with multiple partners in sexual relationships were likely to use contraception. In a rare study, Gyimah et al. (2012) aggregated 1998 and 2003 Ghana DHS to link religions to contraceptive behavior. Among Christians, Muslims, and practitioners/believers in the Traditional religion, the latter religious group used much less or almost no contraception.

We added related hypotheses to the central research questions from existing DHS literature. Based on Kim et al. (2019) findings, we hypothesized that mass media would help women's health planning. Three differences in our study compared to Kim et al.'s. were as follows: We focused on radio (audio literacy) communications due to more approachable areas and expanded the study target to Senegal, Ghana, and Liberia. In our data, time (year) difference could make the effectiveness of messaging more precise and robust.

We observed a possibility of quasi-experimental research, that is, matching covariates or observed characteristics of control and treatment groups in so doing leads to compare a compelling pure experiment effect (Shadish et al., 2002). Adopted from Sougou et al. (2020), we contemplated female respondents' age, autonomy, and partners' health decisions. However, unlike both research pieces (Kim et al. (2019) and Sougou et al. (2020)), we picked other periods of Senegal, 2010-11, 2016, and 2018.

We learned that public and private care of family planning, residence, her and partner's education, religion, and wealth could influence both unmet needs and contraceptive use from the described literature. However, we were not convinced enough that those explanatory variables make a direct impact individually and collectively. Instead, they seemed more like each respondent's observed characteristics or background (Suppose a claim that primary education increases contraception.).

3.5 Methods

In social science research, the biggest challenge is determining the most plausible answer in answering complex human behavioral questions. Manski (1995) explained assumptions could reduce uncertainty and draw valid conclusions. We looked at two questions in one variable: (1)

(Children alive) Suppose you have no child, how many (in integers) would be in your entire life? (2) (No children yet) How many (in integers) of children would be in your whole life? We assumed the number reflects the current and non-existing children for outstanding and realistic household support. From time 0 to 1, a decrease or increase by radio family-planning information communications (knowledge), contraceptive use (use), living children deceased (exogenous shock), and desire for family planning (desire) could change *the number* in regressions.

A reasonable claim could be big swings of the dependent (outcome) variable between years 0 and 1, so naturally, any independent factors make a change course. However, we affirmed no significant swings. The maximum number instead of scaled up from 25 to 30 children against year 0 (n=9560, 2008 Ghana-, 2007 Liberia-, 2010-11 Senegal DHS) and year 1 (n=10,486, 2014 Ghana-, 2013 Liberia-, 2016 Senegal DHS). Alongside the same minimum (=0), the dependent number in mean and standard deviation reduced from 5.4 to 5.32 and 2.44 to 2.21. With the 2018 Senegal DHS, the mean and standard deviation changed from 5.4 to 5.41 and 2.44 to 2.27. The minimum and maximum remained the same despite the change of samples in year 1 (n=10,628). Our attempt is not to reduce the ideal number of children. Instead, we tested how treated groups adjust the family size in children (Assumed no families could afford 25-30 children.).

We applied coarsened exact matching (CEM) to evaluate explanatory factors on the ideal number of children. Exact matching pairs a treated individual with another not treated concerning observed characteristics (Glennerster & Takavarasha, 2013). We tried controlling such covariates as pretest inclusion to the outcome and underscored here again, only including cohabiting, married, pregnant, and fecund women (Mehta, 2001).

Tables 3.1, 3.2, and 3.3 show all the continuous, categorical, and dichotomous variables. Table 3.1 shows our first classification among continuous variables into covariates, dependent, and independent variables. Children (Wantnumchild) that combines actual and ideal number were a covariate in year 0 and the dependent variable in year 1. With the minimum of zero and maximum between 25 and 30, the mean and standard deviations ranged around five and two. The other was the number of living children deceased in years 0 and 1 (Childdeaths). As a role of covariate and independent variable, the mean was 0.42 and 0.49, leaving the minimum (=0) and maximum (=10) the same.

Table 3.1 Continuous Variables of Interest

Variable name	Role	Samples	Minimum	Mean	Std. Dev.	Maximum
Wantnumchild0	Covariate	9560	0	5.4	2.44	25
Wantnumchild1 (with 2016 Senegal)	Dependent variable	10,486	0	5.32	2.21	30
Wantnumchild1 (with 2018 Senegal)	Dependent variable	10,628	0	5.41	2.27	30
Childdeaths0	Covariate	11,014	0	0.49	0.97	10
Childdeaths1 (with 2016 Senegal)	Independent variable	11,594	0	0.43	0.89	10
Childdeaths1 (with 2018 Senegal)	Independent variable	11,685	0	0.42	0.87	10

Categorical information in Table 3.2 continues to explain. First, five Intimate Partner Violence (IPV) cases, a covariate, were accumulated. Forty-six to forty-seven percent had no IPV cases, slightly reversed the aggregation between one and two cases. From two to five, the instances continued proportionately up from 9% to 13%.

Another variable used for the instrumental variable, the wealth index from the poorest to the richest, was disproportionate, i.e., 27% to 14%.

Partners' occupation was in the nominal category. More (approximately 40%) were in agriculture and self-employment than service and professional jobs (34%). The other 26% were in unskilled labor (around 8%) and skilled labor (18%). We expected couples for a living that requires more labor-intensive might want more children than others.

Partners' education was another covariate orderly categorized. Nearly half were uneducated, and for the other half, more were secondary education and higher (39%) than completed primary education (14%).

Respondents' type of earnings was an instrument. Compared to 57% of female workers paid in cash, 16% received in cash and in-kind payment, and 27% were free labor.

Table 3.2 Categorical Variables of Interest

Variable name	Type	Role	Samples per category
IPV cases with Senegal 2016	Ordinal	Covariate	10,503 (46%) for zero cases 2082 (9%) for one 2033 (9%) for two 2447 (11%) for three 2687 (12%) for four 2855 (13%) for five

Table 3.2 Continued

Variable name	Type	Role	Samples per category
IPV cases with Senegal 2018	Ordinal	Covariate	10,727 (47%) for zero cases 2105 (9%) for one 2035 (9) for two 2461 (11%) for three 2583 (11%) for four 2887 (12%) for five
Wilevel with Senegal 2016	Ordinal	Instrumental variable	6001 (27%) at the poorest (=0) 5265 (23%) at the poorer (=1) 4591 (20%) at the middle (=2) 3699 (16%) at the richer (=3) 3052 (14%) at the richest (=4)
Wilevel with Senegal 2018	Ordinal	Instrumental variable	6026 (27%) at the poorest (=0) 5119 (23%) at the poorer (=1) 4663 (21%) at the middle (=2) 3827 (17%) at the richer (=3) 3064 (14%) at the richest (=4)
Partoccupation with Senegal 2016	Nominal	Covariate	8620 (40%) for agricultural and self-employed 7396 (34%) for service and professional 1820 (8%) for unskilled manual 3814 (18%) for skilled manual
Partedu with Senegal 2018	Ordinal	Covariate	10,737 (47%) for No education 3145 (14%) for primary education 8742 (39%) for secondary education and higher
Resptypeearn with Senegal 2016	Nominal	Instrument	4056 (27%) worked for free 2481 (16%) worked in cash and in-kind 8391 (57%) worked in cash only
Resptypeearn with Senegal 2018	Nominal	Instrument	4094 (27%) worked for free 2499 (16%) worked in cash and in-kind 8587 (57%) worked in cash only

Note. IPV cases accumulated five instances/reasons for female respondents to be harmed by partners/husbands: (1) went out without telling them, (2) neglected children, (3) argued with them, (4) refused sex with them, (5) burnt food. Wilevel indicates the levels of household wealth. For the instrumental variable estimations, we treated Wilevel as a continuous variable. Partoccupation includes categories of partners'/husbands' occupations. Partedu is partners'/husbands' education levels. Resptypeearn indicates payment types for female respondents' work.

Table 3.3 contains dichotomous variables. Fifty-three to fifty-four percent of female respondents reported no listening on the radio to information about contraception; the other forty-six to forty-seven percent heard about family planning on the radio for several months. The proportion met a rule of thumb where the almost equal division between treated and control groups.

Contraception in years 0 and 1 was about 10% higher use as time passed (year 0=17%; year 1=27%). Still, most (year 0=83%; year 1=73%) used no contraception. We used the earlier year for a covariate and the later year as an independent variable.

Family-planning preference was dichotomized into "more children wanted" and "no more." In year 0, 70% were in the former category; 30% were in the latter. In year 1, about three percent moved from the former to the latter category (67% wanted more children versus 33% who wanted no more.). We took the earlier preference as a covariate and another year's as an independent variable to want more or fewer ideal children.

Senegal is predominantly Islamic, and the other two countries across Islam, Christianity, and traditional religions. Altogether were 51 to 52% Muslims versus 48 to 49% non-Muslims. We picked Islam as a covariate for religious belief on family size but limited to an indirect cause.

Special district (specialdist) was another binary covariate. About 75% resided outside capital cities. The other 25% were in Accra, Ashanti (Ghana), Monrovia (Liberia), and Dakar (Senegal). We noted the earlier year of Liberia DHS identified Monrovia as an independent district, but later DHS coalesced in South Central.

The questionnaire contains two related questions. Although 49% to 51% answered working, only 19% earned more than partners/husbands. We referred to wives' subordinate socioeconomic status as instruments together with Resptypeearn information.

Table 3.3 Dichotomous Variables of Interest

Variable name	Role	Samples per binary information
Treated (Radio) with Senegal 2016	Treated/ Independent variable	12,256 (54%) Not heard family planning on radio for the last few months 10,351 (46%) heard family planning on radio for the last few months
Treated (Radio) with Senegal 2018	Treated/ Independent variable	11,969 (53%) Not heard family planning on radio for the last few months 10,729 (47%) heard family planning on radio for the last few months
Currentuse0	Covariate	9089 (83%) No contraceptive use 1925 (17%) current contraceptive use
Currentuse1 (with Senegal 2016)	Independent variable	8481 (73%) No contraceptive use 3113 (27%) current contraceptive use
Currentuse1 (with Senegal 2018)	Independent variable	8500 (73%) No contraceptive use 3185 (27%) current contraceptive use
Fpdesire0	Covariate	7730 (70%) More children wanted 3284 (30%) No more children wanted
Fpdesire1 (with Senegal 2016)	Independent variable	7823 (67%) More children wanted 3769 (33%) No more children wanted
Fpdesire1 (with Senegal 2018)	Independent variable	7923 (68%) More children wanted 3760 (32%) No more children wanted
Islam (with Senegal 2018)	Covariate	10,983 (48%) Non-Muslims 11,716 (52%) Muslims
Specialdist (with Senegal 2016)	Covariate	17,027 (75%) Residents Not in capital cities 5581 (25%) Residents in capital cities
Specialdist (with Senegal 2018)	Covariate	17,102 (75%) Residents in Not capital cities 5597 (25%) Residents in capital cities

Table 3.3 Continued

Variable name	Role	Samples per binary information
Respworked (with Senegal 2016)	Instrument	9150 (41%) Respondents currently not working 13,441 (59%) Residents currently working
Respworked (with Senegal 2018)	Instrument	8824 (39%) Respondents currently not working 13,858 (61%) Residents currently working
Earnmls (with Senegal 2016)	Instrument	8789 (81%) earned less than partners/husbands 2078 (19%) earned more than partners/husbands
Earnmls (with Senegal 2018)	Instrument	8953 (81%) earned less than partners/husbands 2128 (19%) earned more than partners/husbands

We ran Stata version 16.1 to apply coarsened exact matching (CEM) and instrumental variable (IV) estimations. These two approaches mirrored opposite for the same purpose. In our experience, IV helped correct the first encounter with CEM. Mehta (2001) asked *what if* our choice of observed characteristics may encompass irrelevant and confusing information. Then, we should simultaneously consider an IV approach to reflect unobserved characteristics. We remark a trade-off between sample size and IV estimation. Because our instruments designated female respondents' socioeconomic, employment, and household wealth, we had to bear much fewer samples included in IV estimation. The smallest were *Earnmls* (n=10,867, 11,081), indicating female respondents earned less or more than partners/husbands.

CEM is a *monotonic imbalance bounding*, which tightens the maximum distribution imbalance by ex-ante selection (Blackwell et al., 2009). Here, ex-ante choice as a basis of coarsening is treatment, that is, family-planning radio communications. Coarsening continues, and each variable becomes closer as the bins or quintiles of empirical distribution narrow.

King and Nielsen (2018) justified that CEM could reduce further imbalance, model dependence, selection bias, and increase efficiency against propensity score matching. Each turns out strict conditions to match the common support area between the exposed and unexposed covariates. The method, based on the congruence principle, releases intuitive and commonplace results. Additionally, Stata 16.1 ran CEM efficiently for a pooled dataset.

In deciding to use or not to use CEM, the first consideration is to check preexisting global imbalance, how much covariates are different between the exposed (treated) and unexposed (control) groups. Suppose k-dimensional data among pretreatment covariates are in $X = (X_1, X_2 \dots X_k)$ format for both groups separately and set the *k*-dimensional frequencies relative to the treated $f_{l1}, f_{l2} \dots f_{lk}$ and the controlled $g_{l1}, g_{l2} \dots g_{lk}$. Then global imbalance (L_1) across all the cell values:

$$\boldsymbol{L_1(f, g) = \frac{1}{2} \sum_{l_1 \dots l_k} |f_{l_1 \dots l_k} - g_{l_1 \dots l_k}|} \qquad \textbf{(3.1)}$$

A maximum of L_1=1 signals perfect separation or both groups have no common area of support. Our initial global imbalance was near 0.7325, a relatively high imbalance, and we hoped it to reduce to closer to L_1=0 after CEM. That turns out:

$$\boldsymbol{L_1(f^m, g^m) \leq L_1(f, g)} \textbf{ where a matched set by } \boldsymbol{f^m} \textbf{ and } \boldsymbol{g^m} \qquad \textbf{(3.2)}$$

In CEM, we acknowledged more notations of the average treatment effect. Suppose a collection of random samples n from N population. And if an individual i received treatment, $T_i = 1$; another no treatment $T_i = 0$. We could observe outcome:

$$\boldsymbol{Y_i = T_i Y_i(1) + (1 - T_i) Y_i(0)} \textbf{ for each unit or individual } \boldsymbol{i} \qquad \textbf{(3.3)}$$

Here, we distinguished $Y_i(1)$ as unobserved for not treated i from $Y_i(0)$ unobserved for treated i.

Now we can determine X_j in k-dimensional data as a column vector of the observed through a pretreatment covariate j for n. $X = X_{ij}$consists of individual samples $i = 1,2 \ldots n$ and covariates or a group of pretreatment variables $j = 1,2 \ldots k$.

In an optimal situation, the treatment plays independently to the outcome from X conditions. In notation, we could draw:

$$\boldsymbol{P\{T \mid X, Y(0), Y(1)\} = P(T \mid X)} \tag{3.4}$$

Here, the treatment effect (TE) for an individual i for $TE_i = Y_i(1) - Y_i(0)$ remained unobserved. Then the sample average TE (SATE) on the exposure should be:

$$\boldsymbol{SATE = \frac{1}{n_T} \sum_{i \in T} TE_i} \tag{3.5}$$

Firestone (2015) added a note of an empirical downside. If we omitted variables or encountered an endogenous problem, a statistical association between the error term and a variable, CEM could be unreliable. A clear setup of matching variables with exposure was imperative.

After CEM, we had three new variables in Stata: cem_strata, cem_matched, cem_weights. All matched (=1) or unmatched (=0) observations (cem_matched) were in designated stratum (cem_strata). And the variable named CEM weights for the use of the causation between independent and outcome variables has unique values in a stratum. Strata differed between the treated and control, and CEM releases weights for analysis (Unmatched cases gave no weight.) (Firestone, 2015).

We also applied a CEM k-to-k match. Unlike CEM, a k-to-k solution prunes or continues to randomly match all CEM-processed cases per stratum until the equal size of treated and controlled individuals (units) remains among all strata (Blackwell et al., 2009).

Sequentially, we also considered an IV approach to reduce endogeneity. An endogenous variable appears when others within the model provoke. Another is exogenous if other variables would not be a cause. Yamano (2009) helped us understand how to construct IV estimations.

Suppose the first-stage regression model:

$$\boldsymbol{y_1 = \alpha_1 y_2 + \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \cdots + \beta_k x_k + \mu} \quad \textbf{(3.6)}$$

Here y_2 variable is endogenous if the variable correlates with the error term μ. IVs are to be uncorrelated with μ and correlated with y_2. We possibly have m IVs. Then IVs, $z = (1, x_1, x_2 \ldots x_k, z_1, z_2 \ldots z_m)$, and y_2 should be correlated.

If we have exogenous variables to y_1, they could be with IVs to explain y_2 in a separate equation. We set:

$$\boldsymbol{y_2 = \delta_0 + \delta_1 x_1 + \delta_2 x_2 + \delta_3 x_3 + \cdots + \delta_k x_k + \delta_{k+1} z_1 + \delta_{k+2} z_2 + \cdots + \delta_{k+m} z_m + \varepsilon} \quad \textbf{(3.7)}$$

After the regression, the reduced form y_2 would have $\hat{y}_2$, which embraces exogenous variables. That is:

$$\boldsymbol{y_2 = \hat{y}_2 + \varepsilon} \quad \textbf{(3.8)}$$

We expect $\hat{y}_2$ remains uncorrelated with μ, correlated with ε. Then we have two separate equations, one correlated with μ and another uncorrelated with μ.

$\hat{y}_2$and Z are expressed:

$$\boldsymbol{\hat{y}_2 = Z\hat{\delta} = Z(Z'Z)^{-1}Z'y_2} \quad \textbf{(3.9)}$$

Suppose we include y_2 and Z in projection of X. Then:

$$\widehat{\boldsymbol{X}} = \boldsymbol{Z}\widehat{\boldsymbol{F}}_{\boldsymbol{km}} = \boldsymbol{Z}(\boldsymbol{Z}'\boldsymbol{Z})^{-1}\boldsymbol{Z}'\boldsymbol{X} = \boldsymbol{P_Z X} \textbf{ where} \tag{3.10}$$

$$\widehat{\boldsymbol{F}}_{\boldsymbol{km}} = \begin{bmatrix} \boldsymbol{\delta_1} & \cdots & \boldsymbol{0} \\ \vdots & \ddots & \vdots \\ \boldsymbol{\delta_{k+m-1}} & \cdots & \boldsymbol{1} \end{bmatrix} \tag{3.11}$$

$\hat{F}_{km}$ is a matrix expressed by (k+m-1)-by-k.

All together, we can express two-stage least squares (2SLS) estimator that incorporates y_2 and the other independent variables with $\hat{X}$ as X's IV estimator. That is:

$$\widehat{\boldsymbol{\beta}}_{\boldsymbol{2SLS}} = (\widehat{\boldsymbol{X}}'\widehat{\boldsymbol{X}})^{-1}\widehat{\boldsymbol{X}}'\boldsymbol{Y} \tag{3.12}$$

In Stata 16.1, we can estimate the 2SLS through two steps instead of one. First, exogenous variables and instruments are to explain the endogenous variable y_2. Next, the estimated $\hat{y}_2$ as a replacement of y_2 run to explain our primary interest (y_1) with all exogenous variables but without instruments.

To evaluate IV estimation, we should consider several post-estimators.
Besides checking coefficients' changes and their standard errors after 2SLS, reliable tests, whether our endogenous-variable choice is exogenous or endogenous, are imperative. By default, a command *estat endonenous* detects if our endogenous selection was right or wrong based on the Durbin and Wu-Hausman tests. The null hypothesis for both is that our endogenous variable was exogenous. Rejection of the null hypothesis implies the variable is genuinely (confidently to us) endogenous. The Durbin test considers the error term's estimated (unadjusted) variance as if all the variables in the model are exogenous. Mirrored opposite, the Wu-Hausman considers unadjusted error variance by endogenous estimators.

Another Stata command, *estat firststage*, provides statistics of the pertinence to the omitted exogenous variables. In turn, it is about the possibility of excluded exogenous variables are instruments. At this stage, we had attention to whether a weak correlation between instruments and an endogenous regressor. The minimum eigenvalue statistic helped determine either fail to reject the null, that is, instruments are weak, or reject, that is our plausible instrument choice. We also considered the F Statistic on the first-stage regression for the concerted significance of exogenous variables' and instruments' coefficients.

The Stata command, *estat overid*, further helps determine any overidentifying issues. If Sargan's and Basmann's χ^2 test statistics show significance at the 5% standard level (p-value), we interpret as our instruments are not valid. Or instruments correlate with μ, the structural error term. Ideally, we should fail to reject the null hypothesis.

3.6 Results

Although both methods' results are in one section, our objective remains steadfast. That is, we wanted to estimate the ideal number of children (wantnumchild) using the variable radio communications in family planning (treatment) with other exogenous variables, those of current contraception (currentuse), desire for more children (fpdesire), and living sons and daughters deceased (childdeaths).

When we first applied CEM, a regression with cem weights provided a wrong assignment for the dependent variable (wantnumofchild). Nor was the treatment effect statistically significant. Binary covariates were residents in capital/not in the capital (specialdist), Muslims (Islam)/non-Muslims, respondents worked/did not work (respworked), respondents' literate/not (literacy), fpdesire, and currentuse. Nominal covariates were partners'/husbands' occupations (partoccupation), and, in ordered categories, were intimate part violence cases (ipvcases), the level of household wealth (wilevel), and partners'/husbands' education (partedu). We ranged zero, two, and ten for childdeaths, and three, six, nine, fifteen, and twenty-five of the wantnumberchild, both in year 0.

We stepped back and searched for improvement. Then we decided the household wealth as the endogenous variable, instrumented by respondents who worked or not (respworked), respondents earned less/more than partners/husbands (earnmls), and types of payroll with nothing/in-kind and cash/cash only (resptypeearn). The reasons were straightforward. Like Sougou et al. (2020), we assumed that female respondents' overall health and family planning decisions depended more on partners/husbands instead of autonomy. Although 39-41% worked, and 73% received in-kind and cash/cash-only payment, only 19% could earn more than cohabitating partners.

After that reflection, we had corrected IV estimation results shown in Tables 3.4 and 3.4. Table 3.4 displayed the results when we included 2008, 2014 Ghana, 2007, 2013 Liberia, and 2010-11, 2016 Senegal DHS.

Table 3.4 IV Estimation for the Number of Ideal Children (with 2016 Senegal DHS)

Independent Variable	Coefficient	*SE*	95% *CI*		*p*
			LL	*UL*	
Intercept	7.556	0.171	7.22	7.89	<0.001
Wilevel[a]	-0.757	0.062	-0.878	-0.636	<0.001
Currentuse[b]	-0.15	0.051	-0.25	-0.05	0.003
Fpdesire[c]	-0.465	0.045	-0.554	-0.376	<0.001
Treated (Radio)[d]	-0.189	0.053	-0.292	-0.085	<0.001
Childdeaths[e]	0.331	0.027	0.278	0.384	<0.001

Note. *N* = 9863, Wald chi (5) = 967.15, Prob. > chi2 = <0.001, R-squared = 0.1026, Root MSE = 2.126. *SE* = standard error CI = confidence interval; *LL* = lower limit; *UL* = upper limit, *p* = p-value

[a] Household wealth treated as continuous for IV estimation [b] 0 = No method, 1 = contraceptive method [c] 0 = wants more children, 1 = no more [d] 0 = Not heard, 1 = heard [e] Number of living children deceased
Instrumented: wilevel, Instruments: resptypeearn, respworked, earnmls, currentuse, fpdesire, treated, childdeaths
The Stata regression table is in the appendix.

As shown in Table 3.4, the endogenous variable, household wealth, reduced future children's number by 0.757. Compared to no users, others who use contraceptive methods likely mitigate as many as 0.15. If a female did not want any more children, the number continued to drop by 0.465 comparing to her sister, who wanted more. The treatment variable of our interest, radio communications, also reduced the future children by 0.189. However, not all explanatory variables decreased the number of future children. For a couple of a child loss, they are likely to have 0.331 more. We observed instruments adjusted standard errors and coefficients correctly. For 9863 observations, the endogenous and all exogenous were statistically significant at the 99% confidence level.

In post-estimation, our first focus was whether the household wealth (wilevel) is exogenous or endogenous. Under the null hypothesis statement, that is, wilevel as exogenous, both Durbin and Wu-Hausman statistics shown in Figure 3.1 suggested wilevel was an endogenous variable (We rejected the null hypothesis at the 1% alpha level.).

Then, we examined whether our instruments had sufficient explanatory power. Among various statistics in Figure 3.2, we highlighted the F statistic and p-value on first-stage regression summary statistics and minimum eigenvalue statistic. Our first-stage regression was:

$$\boldsymbol{wilevel_i = \delta_0 + \delta_1 currentuse_i + \delta_2 fpdesire_i + \delta_3 treated_i + \delta_4 childdeaths_i + \delta_5 2.restypeearn + \delta_6 respworked + \delta_7 earnmls + \varepsilon} \qquad \mathbf{(3.13)}$$

The information F (3, 9855) indicates an F statistic for the concerted significance of instruments' coefficients, δ_5, δ_6, and δ_7. The statistic (228.71) and p-value (<0.001) implied statistical significance beyond the 1% alpha level, which meant our IVs had explanatory robustness for $wilelvel$, that is, our endogenous variable and the dependent variable on the first regression. We assumed the test controlled the other independent variables. Also, the rejection of another null hypothesis (H_0: Instruments are weak.) at the 1% alpha level meant our instruments were robust. Here the minimum eigenvalue statistic was 228.71.

Equally important to the previous post-estimation tests, Sargan and Basman tests were essential to determine if our instruments had any overidentifying problems. In Figure 3.3, both test statistics provided 0.78 (and p-value: 0.677), and we failed to reject the null hypothesis, which signified no correlation between our instruments and the structural error, μ.

Figure 3.1 Endogeneity Tests (1)

```
Tests of endogeneity
Ho: variables are exogenous

Durbin (score) chi2(1)          =  31.6241  (p = 0.0000)
Wu-Hausman F(1,9856)            =  31.7033  (p = 0.0000)
```

Figure 3.2 Instrument Validity Tests (1)

First-stage regression summary statistics

Variable	R-sq.	Adjusted R-sq.	Partial R-sq.	F(3,9855)	Prob > F
wilevel	0.1263	0.1257	0.0651	228.71	0.0000

Minimum eigenvalue statistic = 228.71

Critical Values # of endogenous regressors: 1
Ho: Instruments are weak # of excluded instruments: 3

	5%	10%	20%	30%
2SLS relative bias	13.91	9.08	6.46	5.39

	10%	15%	20%	25%
2SLS Size of nominal 5% Wald test	22.30	12.83	9.54	7.80
LIML Size of nominal 5% Wald test	6.46	4.36	3.69	3.32

Figure 3.3 Overidentifying Restriction Tests (1)

```
Tests of overidentifying restrictions:

Sargan (score) chi2(2) =  .780962  (p = 0.6767)
Basmann chi2(2)        =   .78039  (p = 0.6769)
```

To test for consistent results, we re-ran the same regressors and post-estimations with the 2018 Senegal DHS instead of 2016's.

Overall, in Table 3.5, independent variables' coefficients did not differ much from the previous estimation. We had more observations (n=10,110) than the previous (n=9863). Two exogenous variables, currentuse and treated, had bit higher p-values, i.e., 0.015 and 0.007. But here, we had no issues rejecting the null hypothesis, at least at the 5% alpha level.

Table 3.5 IV Estimation for the Number of Ideal Children (with 2018 Senegal DHS)

Independent Variable	Coefficient	*SE*	95% *CI*		*p*
			LL	*UL*	
Intercept	7.562	0.169	7.23	7.89	<0.001
Wilevel[a]	-0.743	0.061	-0.863	-0.624	<0.001
Currentuse[b]	-0.124	0.051	-0.224	-0.024	0.015
Fpdesire[c]	-0.497	0.045	-0.585	-0.408	<0.001
Treated (Radio)[d]	-0.142	0.053	-0.245	-0.039	0.007
Childdeaths[e]	0.337	0.027	0.284	0.389	<0.001

Note. *N* = 10,110, Wald chi (5) = 952.26, Prob. > chi2 = <0.001, R-squared = 0.1069, Root MSE = 2.136. *SE* = standard error CI = confidence interval; *LL* = lower limit; *UL* = upper limit, *p* = p-value
[a] Household wealth treated as continuous for IV estimation [b] 0 = No method, 1 = contraceptive method [c] 0 = wants more children, 1 = no more [d] 0 = Not heard, 1 = heard [e] Number of living children deceased
Instrumented: wilevel, Instruments: resptypeearn, respworked, earnmls, currentuse, fpdesire, treated, childdeaths
The Stata regression table is in the appendix.

Durbin and Wu-Hausman's statistics re-appeared in Figure 3.4, related to the results of Table 3.5. We again rejected the null hypothesis based on statistics (27.65, 27.71) and p-values less than 0.001. Our endogenous choice, wilevel was correct once again.

Information on post-estimation continued for the second IV estimation. In Figure 3.5, the p-value (<0.001) for the F (3,10102) statistic reaffirmed the explanatory robustness of IVs for *wilelvel*. The minimum eigenvalue statistic (238.62) helped determine our instruments still are robust.

Figure 3.4 Endogeneity Tests (2)

```
Tests of endogeneity
Ho: variables are exogenous

Durbin (score) chi2(1)          =  27.6574  (p = 0.0000)
Wu-Hausman F(1,10103)           =  27.7141  (p = 0.0000)
```

Figure 3.5 Instrument Validity Tests (2)

First-stage regression summary statistics

Variable	R-sq.	Adjusted R-sq.	Partial R-sq.	F(3,10102)	Prob > F
wilevel	0.1307	0.1301	0.0662	238.616	0.0000

Minimum eigenvalue statistic = 238.616

Critical Values — # of endogenous regressors: 1
Ho: Instruments are weak — # of excluded instruments: 3

	5%	10%	20%	30%
2SLS relative bias	13.91	9.08	6.46	5.39

	10%	15%	20%	25%
2SLS Size of nominal 5% Wald test	22.30	12.83	9.54	7.80
LIML Size of nominal 5% Wald test	6.46	4.36	3.69	3.32

The score of Sargan and Basman tests in Figure 3.6 was 0.124, and 0.94 as its p-value. Again, we failed to reject the null hypothesis and decided no correlation between our instruments and the structural error, μ.

Figure 3.6 Overidentifying Restriction Tests (2)

```
Tests of overidentifying restrictions:

Sargan (score) chi2(2) =  .124454  (p = 0.9397)
Basmann chi2(2)        =  .124357  (p = 0.9397)
```

Now, we came back to CEM. Aside from the IVs and the endogenous variable, we chose the covariates carefully. Because of variant time, we put times zero and one on a few variables. In time one, the deceased children (childdeaths1), the ideal children (wantnumchild1), family-planning desire (fpdesire1), and contraceptive use (currentuse1) differed from year 0, for later dependent and explanatory variables. Two discernable points here. First, we used the same covariates in year 0 for CEM. Second, we already used the same variables for IV estimations.

Other covariates were residences in capital cities or not (specialdist), Muslims/non-Muslims (Islam), partners'/husbands' occupations (partoccupation), partners'/husbands' education (partedu), and the stacked (summed) intimate partner violence cases (ipvcases). Figure 3.7 presents each and a group of covariates' initial imbalance, divided by controlled (0=not exposed to radio communications in family planning) and treated (1=radio communicated in family planning) groups. Notice we specified (1) and (2) after titles again to show the results with the Senegal 2016 (former) and 2018 (latter).

Figure 3.7 shows that the first multivariate L_1 distance was 0.5224 (reduced from the initial imbalance, 0.7325), which still implied a high imbalance between them. Individually, the most considerable discrepancy was the number of wanted children in year 0 (L_1= 0.148). The mean between the control and treat was up to -0.6194. The quintile difference remained at the third quintile.

IPV cases (ipvcases) left an L_1 statistic (0.137) with the difference at the median and third quintiles (mean difference: -0.5497). Partoccupation marked a similar L_1 statistic (0.131) but a lower mean difference of 0.1592. Another covariate, Islam/non-Islam, also left a similar imbalance of 0.1298, a lower mean difference of -0.1298. The basis, where two groups resided (specialdist), caused a 0.1153 imbalance, the same mean difference, and the third quintile difference.

Below 0.1 of imbalance, three covariates emerged. The imbalance of contraception in year 0 (currentuse0) was 0.086 (likewise mean difference), leaving no quintile difference. At lower imbalance of 0.052, was the preference of family planning in year 0 (fpdesire0). At the lowest imbalance of 0.036, was the number of deceased children in year 0 (childdeaths0), and unlike the aforementioned two covariates, the mean difference (-0.063) differed from their imbalance. Two notices here: the lowest imbalance group was later for independent variables; quintiles were indifferent among the covariates.

Figure 3.8 displays another initial imbalance with the 2018 Senegal DHS as year 1, instead of its 2016 information in year 1. This time, we substituted the partner's/husband's education for his occupation, as expected to reduce the overall L_1 statistic or imbalance. The primary reason was to minimize multivariate and univariate L_1 statistics, albeit almost alike

(=0.5218). Respectively, the partner's/husband's education yielded an imbalance of 0.2336 with a mean difference of 0.4354. Others remain imbalanced similar to the previous.

Figure 3.7 Initial Imbalance (1)

Multivariate L1 distance: .5224008

Univariate imbalance:

	L1	mean	min	25%	50%	75%	max
specialdist	.11528	.11528	0	0	0	1	0
childdeaths0	.03649	-.06331	0	0	0	0	0
fpdesire0	.05209	.05209	0	0	0	0	0
islam	.12982	-.12982	0	0	-1	0	0
partoccupation	.13076	.15917	0	0	0	0	0
ipvcases	.13712	-.54968	0	0	-1	-1	0
currentuse0	.08628	.08628	0	0	0	0	0
wantnumchild0	.14791	-.61944	0	0	0	-1	0

Figure 3.8 Initial Imbalance (2)

Multivariate L1 distance: .52184629

Univariate imbalance:

	L1	mean	min	25%	50%	75%	max
specialdist	.11848	.11848	0	0	0	1	0
childdeaths0	.03248	-.06079	0	0	0	0	0
fpdesire0	.05266	.05266	0	0	0	0	0
islam	.13466	-.13466	0	0	-1	0	0
partedu	.23355	.43543	0	0	2	0	0
ipvcases	.13903	-.5569	0	0	-1	-1	0
currentuse0	.0854	.0854	0	0	0	0	0
wantnumchild0	.14792	-.61361	0	0	0	-1	0

After initial imbalance checks, we ran CEM. The matching summaries are in Figures 3.9 and 3.10. The former with the Senegal DHS 2016 had a change of multivariate L_1 statistic to 0.148. The initial coarsened exact matching went well, considering the rule of thumb under 0.2. Out of the total 22,608 cases (control=12,257 | treatment=10,351) in 1575 strata, 21,402 (control=11,405 | treatment=9997) and 777 strata became matched. We highlighted the match went well for two reasons. First, the CEM algorithm dropped fewer treated cases because we were aware of more cases on the other side before CEM. Second, the algorithm dropped only 1206 cases so that we could have affordable sizes for both groups.

As we expected, most binary and categorical covariates for non-parametric matching, those univariate L_1 statistics became 14-15-digit decimals (likewise the mean differences) after CEM. The two continuous-type covariates, childdeaths0 and wantnumchild0, had L_1 statistics of 0.006 and 0.016, univariately. All the zeroes and omitted numbers in the quintiles/percentiles showed two groups (controlled and treated), almost matched as alike after CEM.

The latter matching summary confirmed this similarity. The multivariate L_1 imbalance went down slightly to 0.133 among 22,699 cases (control=11,970 | treatment=10,729) in 1273 strata. For CEM, the algorithm dropped fewer treated cases (=251) than controlled cases (=699) or matched both groups more equal in 653 strata. Two L_1 statistics of childdeaths0 and wantnumchild0 slightly went down to 0.003 and 0.013.

Figure 3.9 CEM Matching Summary (1)

```
Matching Summary:
-----------------
Number of strata: 1575
Number of matched strata: 777

              0      1
      All  12257  10351
  Matched  11405   9997
Unmatched    852    354


Multivariate L1 distance: .14576688

Univariate imbalance:

                      L1       mean        min        25%        50%        75%        max
   specialdist   3.1e-14  -5.7e-15          0          0          0          0          0
  childdeaths0    .00567   -.00388          0          0          .          .          .
     fpdesire0   3.2e-14  -4.4e-15          0          0          .          .          .
         islam   1.8e-14  -1.4e-14          0          0          0          0          0
partoccupation   1.9e-14   5.3e-15          0          0          0          0          .
      ipvcases   2.4e-14  -1.8e-14          0          0          0          0          0
   currentuse0   3.1e-14  -2.9e-15          0          0          .          .          .
 wantnumchild0     .0163   -.01588          0          0          .          .          .
```

Figure 3.10 CEM Matching Summary (2)

```
Matching Summary:
-----------------
Number of strata: 1273
Number of matched strata: 653

              0      1
      All  11970  10729
  Matched  11271  10478
Unmatched    699    251


Multivariate L1 distance: .13300709

Univariate imbalance:

                    L1     mean      min      25%      50%      75%      max
  specialdist  5.0e-14  2.0e-14        0        0        0        0        0
 childdeaths0   .00338  -.00254        0        0        .        .        .
    fpdesire0  5.3e-14  9.8e-15        0        0        .        .        .
        islam  2.8e-14  2.8e-14        0        0        0        0        0
      partedu  3.4e-14  8.2e-14        0        0        0        0        .
     ipvcases  4.5e-14  4.8e-14        0        0        0        0        0
  currentuse0  5.4e-14  6.3e-15        0        0        .        .        .
wantnumchild0   .01296  -.00729        0        0        .        .        .
```

K-to-K matching summaries are in Figures 3.11 and 3.12. The option exhaustively equally matches the controlled and treated cases. The former k-2-k matching with the 2016 Senegal DHS equalized 6812 cases on both groups and generated 0.068 of multivariate L_1. The latter k-to-k matching summary with the 2018 Senegal DHS matched 6840 individuals equally on two sides, left 0.064 of multivariate L_1.

Figure 3.11 K-to-K Matching Summary (1)

```
Matching Summary:
-----------------
Number of strata: 3205
Number of matched strata: 1047

               0      1
      All  12257  10351
  Matched   6812   6812
Unmatched   5445   3539


Multivariate L1 distance: .06782149

Univariate imbalance:

                     L1      mean       min       25%       50%       75%       max
   specialdist        0         0         0         0         0         0         0
  childdeaths0        0         0         0         0         .         .         .
     fpdesire0        0         0         0         0         .         .         .
         islam        0         0         0         0         0         0         0
partoccupation        0         0         0         0         0         0         .
      ipvcases        0         0         0         0         0         0         0
   currentuse0        0         0         0         0         .         .         .
 wantnumchild0   .01262   -.00705         0         0         .         .         .
```

Figure 3.12 K-to-K Matching Summary (2)

```
Matching Summary:
-----------------
Number of strata: 2744
Number of matched strata: 928

               0      1
      All  11970  10729
  Matched   6840   6840
Unmatched   5130   3889


Multivariate L1 distance: .06418129

Univariate imbalance:

                    L1     mean      min      25%      50%      75%      max
  specialdist        0        0        0        0        0        0        0
 childdeaths0        0        0        0        0        .        .        .
    fpdesire0        0        0        0        0        .        .        .
        islam        0        0        0        0        0        0        0
      partedu        0        0        0        0        0        0        .
     ipvcases        0        0        0        0        0        0        0
  currentuse0        0        0        0        0        .        .        .
wantnumchild0   .01067  -.00658        0        0        .        .        .
```

Taken together with CEM weights, we re-ran multiple linear regressions. The dependent and exogenous variables remain the same as IV estimations. Two differences were here. For one, with covariate information (background characteristics of years 1 and 2) and year 0's (for year 1's explanatory variables), we estimated coefficients in year 1. For two, we no longer needed IVs and any more endogenous variables.

We proposed two different regression results. Table 3.6 shows Ghana 2014, Liberia 2013, and Senegal 2016 as year 1, and Table 3.7 included the same year's Ghana and Liberia but the Senegal 2018. Regardless, statistical significance (p-value<0.001) of all independent variables proved explanatory power to our dependent variable, the number of ideal children. The number of degrees of freedom (=4) remained the same to and in-order result arrangements in both figures. However, sample sizes differed from the former (=7593) from the latter (=7601).

Compared to IV estimations, the role of explanatory variables, especially for reduction or addition to the dependent variable, remained identical. However, the degree per explanatory variable was not the same. Here, CEM-weighted regression coefficients commonly made reduction variables more reduced, and another addition variable more increased. The IV estimations' coefficients for contraception (currentuse) were between -0.124 and -0.15, but year 1's estimate changed from -0.286 to -0.324. And our primary interest, radio communications in family planning, had a higher impact on reducing the number of ideal children as many as -0.229 to -0.25 against IV estimations' -0.142 and -0.189. Those who no longer want more children were predicted to reduce future children here by 0.536 and 0.608, compared to 0.465 and 0.497.

A child deceased caused more children to want in the future here from 0.536 to 0.569 instead of IV regressions' 0.331 to 0.337.

Table 3.6 CEM-weighted Multiple Regression for the Number of Ideal Children (1)

Independent Variable	Coefficient	*SE*	95% *CI*		*p*
			LL	*UL*	
Intercept	5.577	0.042	5.487	5.654	<0.001
Currentuse1[a]	-0.324	0.057	-0.434	-0.213	<0.001
Fpdesire1[b]	-0.51	0.054	-0.616	-0.403	<0.001
Treated (Radio)[c]	-0.25	0.05	-0.348	-0.153	<0.001
Childdeaths1[d]	0.536	0.029	0.48	0.592	<0.001

Note. *N* = 7593, F (4, 7588) = 126.2, Prob. > F = <0.001, R-squared = 0.0574, Adjusted R-squared = 0.0569, Root MSE = 2.167. *SE* = standard error CI = confidence interval; *LL* = lower limit; *UL* = upper limit, *p* = p-value
[a] 0 = No method, 1 = contraceptive method in year 1 [b] 0 = wants more children, 1 = no more in year 1 [c] 0 = Not heard, 1 = heard [d] Number of living children deceased in year 1
The Stata regression table is in the appendix.

Table 3.7 CEM-weighted Multiple Regression for the Number of Ideal Children (2)

Independent Variable	Coefficient	*SE*	95% *CI*		*p*
			LL	*UL*	
Intercept	5.662	0.043	5.578	5.747	<0.001
Currentuse1[a]	-0.286	0.057	-0.397	-0.175	<0.001
Fpdesire1[b]	-0.608	0.056	-0.717	-0.499	<0.001
Treated (Radio)[c]	-0.23	0.05	-0.329	-0.13	<0.001
Childdeaths1[d]	0.569	0.03	0.511	0.627	<0.001

Note. *N* = 7601, F (4, 7596) = 121.5, Prob. > F = <0.001, R-squared = 0.0601, Adjusted R-squared = 0.0596, Root MSE = 2.206. *SE* = standard error CI = confidence interval; *LL* = lower limit; *UL* = upper limit, *p* = p-value
[a] 0 = No method, 1 = contraceptive method in year 1 [b] 0 = wants more children, 1 = no more in year 1 [c] 0 = Not heard, 1 = heard [d] Number of living children deceased in year 1
The Stata regression table is in the appendix.

3.7 Conclusions and Discussion

We value our study in three aspects:

1. Despite the limited information of the DHS as secondary datasets, aggregated data helped us find and interpret results consistent either by an unobserved approach, i.e., IV estimations, and another observed (quasi-experimental) approach, i.e., CEM-weighted multiple regressions. We recall those approaches are seemingly unrelated or two opposite mirrors for the same purpose.
2. As we hypothesized, contraception and the desire for no additional children reduced ideal children. Together, our treatment variable, communicating family-planning information by radio for months, decreased the number of children from zero to 30.
3. As a reality check, our expectation that more children wanted if a couple lost their children was proved correct.

Slightly different, compared to IV estimations, CEM-weighted information of year 0's and other covariates made robust causation of multiple linear regressions in year 1.

We recall the keynote of Sougou et al. (2020). Their finding was that wives/female partners' household and health decisions were secondary to their cohabitating partners/husbands. This helped us to set female respondents' independent socioeconomic information on working/not working, payment types, and less or more earnings than their husbands as instruments of our endogenous variable, household wealth. Those hardly imagined considering our binary DHS information, only 19% of married/cohabitating women earned more than husbands/partners but worked well as an instrument. Also, we referred to observed characteristics of partners/husbands as covariates. We expect more in-field studies and other DHS analyses to support or reject our findings.

We do not overemphasize family planning as the best option for sustainable development. But with expectations for stagnant food production and continued population growth, family planning could be an alternative development option.

3.8 Implications and Recommendations

Our implications and recommendations are related to and based on conclusions and discussions. Policymakers should consider family-planning policies for a couple, instead of a husband or a wife. A collaborative decision-making process is imperative.

We chose radio as a medium of family-planning information because of diffusion and dissemination power. We recommend that similar or better delivery tools communicate accurate family-planning information to reach more target populations, toward more met needs among families.

Asiedu (2012) supports our recommendation of a bottom-up approach. More homemakers, female farmers, and others working outside houses who are illiterates, communicated in local dialects, and are familiar with indigenous cultures could get informed by local radio stations. Radio communications can take a couple with other ICTs, including computers, smartphone devices, and other electric equipment that store, manage, and transport a large family planning information volume. Radio producers, hosts, and family planning workers hear listeners' concerns and interests, learn from up-to-date news, filter unnecessary and inaccurate information, and share and communicate with listeners. This way, husbands, wives, and partners reduce the knowledge gap and pursue family planning with the same or similar information and perceptions.

CHAPTER IV

EMPOWERING RURAL FEMALES

4.1 Introduction

The United Nations Association (2017) repeatedly urged that policymakers provide actionable ideas for the underserved population. The United Nations' Sustainable Development Goals highlight that all people raise their voices and stand as equals. To assist, we should identify variables that may improve social and economic status. Equally important, negative factors could deteriorate the quality of life. Females in rural areas are often powerless, voiceless, and dependent on their families and society. Multilateral, bilateral, and bipartisan efforts must empower all women, count them in reducing poverty and hunger, and help them achieve well-being (Nwanze, 2017, p. 3; The United Nations Association, 2017, pp.72-73).

Urbanization is a dynamic process near the capital city into education, politics, and business hubs. Urban dwellers have more opportunities to pursue a healthy, productive life while vulnerable rural populations live under yesteryear's living conditions.

The Central Intelligence Agency (2018) reported approximately 20 percent of Ghanaians live in Accra and Kumasi, located in southern Ghana. Liberia, another West African country, is densely populated in the capital city. Monrovia alone accommodates about 30 percent of all Liberians. Senegal follows a similar demographic trend. Over 20 percent settle in Dakar, the capital city. The urban population reaches 30 percent if we consider neighboring regions of Diourbel and Thiès.

African Development Bank (2015) underscored that Africa's middle class has more than doubled in three decades: from 66 million to 137 million between 1980 and 2010. Explicitly, Ghana had 15 percent in 2014, compared to eight percent in 2004 ("Few and Far between," 2015).

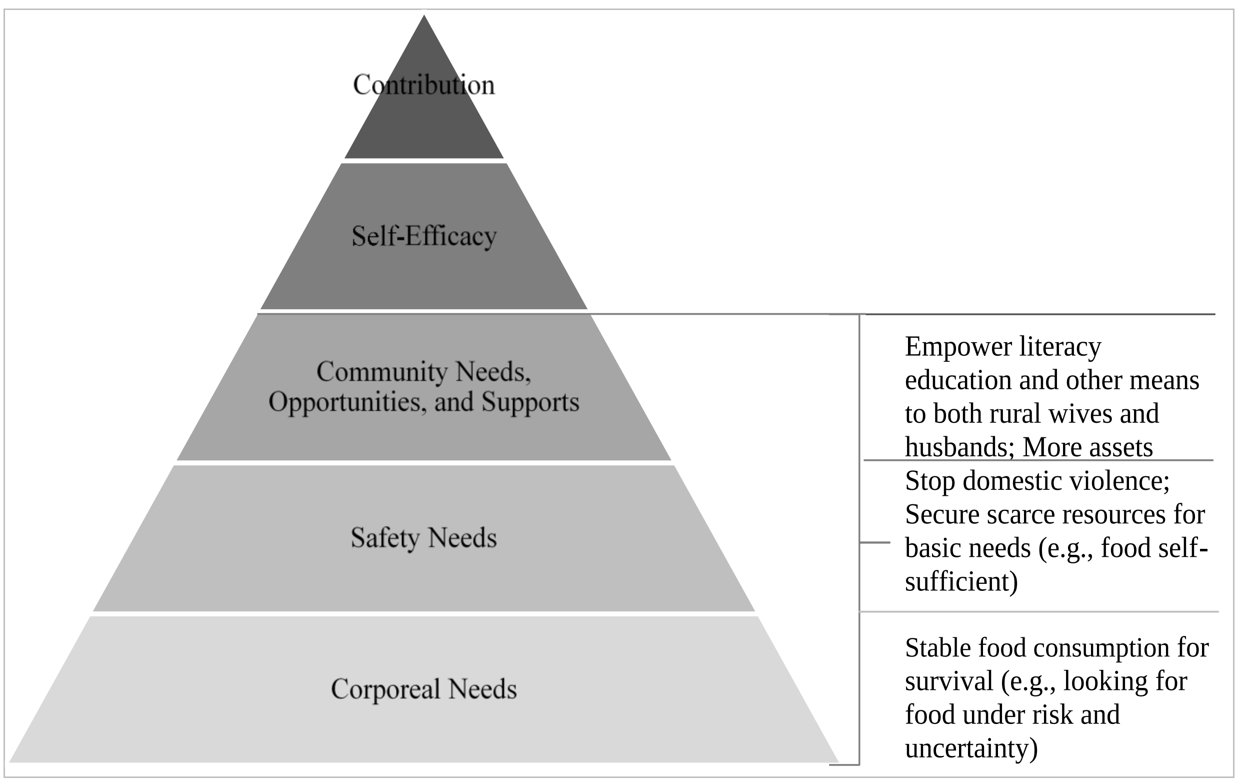
Residents in Accra and Kumasi, the areas near Dakar, and Monrovia can achieve higher incomes, expand the private sector, and increase their living standards. Further, residents there demand better governance and ways to narrow gender inequality and other social problems (African Development Bank, 2015).

Maritz and Probyn (2017) revisited to identify commonality relationships. Foremost, over 60 percent of urban respondents indicated no interest in resettling their rural hometowns. Females realize social opportunities equal to those of their male counterparts. They pursue higher education and their careers, delay marriage, and get involved in crucial household decisions. One phenomenon is that urban couples' households average 3.6 persons, implying small-sized families of fewer than two children. Hence, urban parents can allocate more resources to each child's nutrition and schooling. Notably, both parents and children of younger generations believe that education is a prerequisite to achieving self-esteem and self-actualization.

McLeod (2017) explained Maslow's Hierarchy of Needs in a five-tier pyramid that is publicly available. Figure 4.1, entitled Social Hierarchy of Needs, is a modified version that displays different tiers (peak) from self-actualization to the contribution, (second top tier) self-esteem needs to self-efficacy, (third/middle) belongingness and love needs to community needs, opportunities, and support, (lower) safety needs, and (bottom) physiological needs to corporeal needs. Explanations per tier in Figure 4.1 accordingly differ from the original version.

Some urbanites achieve the top triangle—self-actualization. A person could maximize his or her talents and contribute to society merely with reasonable motivation. He or she should believe in personal worth and abilities. Motivation expands self-esteem through self-efficacy. The second layer cannot exist unless a person realizes community needs and social and socioeconomic opportunities and acquires skills, knowledge, and other means to increase human capital to support the family, community, and government. The top two layers of Maslow's hierarchy are intrinsic to the ability and willingness of a person. Contrastingly, the three stages below are external factors, and each is a precondition for inner motivation or the advancement of the social hierarchy of needs.

Figure 4.1 Social Hierarchy of Needs



Note. Adapted from McLeod (2017)

4.2 Objective

Our objective was to classify extrinsic factors from the literature and study data related to wealth. Data reports as the primary source highlight the urban-rural disparity of Ghana, Senegal, and Liberia in the past. Next, this study reports women's nutritional and socioeconomic status, explained by identified external factors and policy implications based on findings. The social hierarchy of needs influenced the entire examination.

4.3 Literature Review

Dorward et al. (2004) pointed out the rate of female illiteracy as a severe issue. Fuest (2008) raised a concern of most young, marginalized, and illiterate females for geographic isolation from the urban center and conflict. For instance, Senegalese females in the Casamance region, far from the capital city, have remained underserved, uneducated, with low social status, perhaps because of a lack of social support during internal conflict. Liberia experienced harsher, widespread suffering between 1989 and 2003. Unequal economic and political power—Americo-Liberians across other ethnic groups—triggered a civil war. During the period, almost all farms were abandoned and destroyed (Ahn et al., 2017). Fuest (2008) found approximately 2.5 million Liberians lost their homes. In Ghana, female illiteracy is prevalent in rural areas regardless of somewhat consistent economic growth in the country as a whole.

Early marriage causes a vicious cycle, one generation to another. Young wives never complete primary education and early marriages lead to lower education, not only for themselves and their children, but also for other young women not in a union or marriage. Delprato et al. (2017) reiterated the value of a community location near schools, the relationship to the husband's level of educational achievements, and the diversity of job opportunities. If a wife lives in a rural area, her social status is low, she has an uneducated spouse, and the two engage in traditional agriculture for a living. Worse is that rural females are malnourished, pass down poverty to children, and have higher fertility and infant mortality (Delprato et al., 2017; Flückiger and Ludwig, 2017; Otoo-Oyortey and Pobi, 2003; Parsons et al., 2015).

Loaiza and Wong (2012) reported 33% of Senegalese, 38% of Liberian wives 20 to 24 years old got married or into a union by age 18 between 2000 and 2011. Early marriage in Ghana was below 30%. Nwanze (2017) highlighted those rural communities neglect to improve inequalities, and a woman alone cannot overcome multi-faceted cultural obstacles.

To rural women, complete agricultural transformation means that communities provide such infrastructure as electricity, telephone, and water supply facilities. Nwanze (2017) called this "full autonomy" because using these assets allows women to spend less time at home and farm but additional hours at school. The safety of females precedes community needs, opportunities, and supports. Diallo and Voia (2016) found women had prolonged exposure to intimate partner violence (IPV). The threat of and violence from husband or partner is such that a wife hardly resists.

Sahn and Stifel (2003) studied 24 countries of the Demographic Health Surveys (DHS) published in the 1980s and 1990s to compare rural and urban residents' living standards. The indicators differentiating the areas were household assets, education, and health.

4.4 Data Description

Ghana, Liberia, and Senegal DHS revisited; the DHS final reports provided additional information. The DHS reports in the 1980s stated the differences between urban and rural areas and the side effects of urbanization. In the 1986 Liberia DHS report, young women in the capital city, Monrovia, delayed marriage one-and-a-half years, gave fewer births, used effective contraceptive methods, and had better nutrients than their rural counterparts were uneducated and married young. Mothers in urban regions raised infants with care, and children were better nourished than were those in rural ones. Rural communities did not emphasize literacy education nor send their children to schools, especially daughters, based on traditional and cultural beliefs. Polygyny—one husband with several wives—was more prevalent in rural villages. Religious affiliation also was related to the social status of Liberian females. Most urban females were Christians. Overall, women from Christian communities had more chances for post-secondary education than women in other areas or other religious affiliations, i.e., over 20% Muslims, 18% traditional, and 25% with no religious affiliation. And most important, increased urbanization resulted from rapid rural migration. In a decade, from 1974 to 1984, the urban population increased from 29% to 39% of Liberia's total population (Chieh-Johnson et al., 1988).

The same or a similar historical trend was in the other two countries. Ghana Statistical Service– (GSS) and Institute for Resource Development/Macro Systems (1989) addressed the Greater Accra and Eastern regions, i.e., near the capital city, that accommodated young, highly educated husbands who had managerial, professional, and specialized jobs.

Only 16% not educated in either of these urban regions, but the rate soared to around 80% in Upper and Northern regions. Urban wives were also highly educated. On average, urban couples planned families had fewer children than couples in rural areas and gave their children proper education and nutrition. Contrastingly, the report stated that most families in rural areas believed having a child under God's decision.

Circumstances in Senegal were not much different from the ones described above. One distinction was a persistent drought that caused a massive exodus from rural areas to cities. In a short period, Dakar's population, the capital city, grew by 5%, mostly due to the immigration of peanut farmers and their households from the North. Sudden displacement notwithstanding, urbanization has been continuous near Dakar since the 1970s. Another difference is a religious belief. Islam was and still is the dominant religion in Senegal. Forty-six percent of young women in the West (more densely populated areas) were in school, while fewer than seven of one-hundred daughters in rural areas could attend primary school. In Dakar, around ninety of one hundred could read and write whole sentences, but the region farthest from Dakar saw barely seven of one hundred who achieved literacy.

Educated mothers preferred having fewer children, delivering babies at medical facilities, and benefiting from modern medicine. Like urban Liberia and Ghana, child mortality was the lowest in Dakar (Ndiaye et al., 1988). Urbanization has continued, and Cooke et al. (2016) remarked that the poverty gap between urban and rural households had quadrupled since the 1990s.

4.5 Summary Statistics

Our analysis focused on the nutritional, demographic, and socioeconomic status of 15- to 49-year-old females since the early 2000s. We used 2008 and 2014 Ghana, 2007 and 2013 Liberia, and 2005, 2010-11, 2012-13, 2014, 2015, and 2016 Senegal DHS datasets. The DHS is ideal for comparing countries and regions within a country (African Development Bank, 2015; Neuman et al., 2011).

We show body mass index (BMI), wealth, full-autonomy assets (Assets), and intimate partner violence (IPV) in summary tables. Table 4.1 contains BMI information by residence. Rural areas had more underweight Ghanaian and Liberian females than their urban sisters, who are 15-49 years old. In Senegal, more women were malnourished than in the other two countries, irrespective of regions.

In six years, rural Liberia had the most significant increase in its obese population; obesity more than tripled: 3.27% in 2007 to 10.97% in 2013. The obese people in urban areas more than doubled: 7.41% to 17.65% in the same period. As expected, rural and urban Ghana had more overweight and obese women than in the other two countries. Based on 2014 Ghana DHS data, five out of ten in urban areas were overweight or obese.

This inequality study depended on and primarily consisted of social indicators that influence a person's well-being, and household wealth is informative. Table 4.2 shows nearly sixty to more than seventy percent of females in rural areas, 15- to 49-year-olds, were below median wealth (comparing the poorest and poorer groups, the lowest was Senegal in 2012-13, 58.69%, and the highest was Liberia in 2013, 72.56 %.). Percentages in urban areas were the opposite. Over 80% of 15- to 49-year-old urban dwellers were in the richer and wealthiest groups, according to 2003 Ghana-, 2007 Liberia- and 2005 Senegal DHS data.

Seven dichotomous variables—no (0) or yes (1) to operate electricity, radio(s), television(s), refrigerator(s), bicycle(s), motorcycle(s), and vehicle(s) in respondents' houses—were explanatory variables for the study. They represent "full-autonomy assets," which could ease the burden of the assigned chores at family farms and homes (Nwanze, 2017). We summed them. For instance, if a respondent owned all assets, we score her seven for the "Assets" variable. A score of zero was the reverse case when one owned none of the assets. Table 4.3 displays the percentage of women who owned individual assets by residence.

Rural Liberians had little electricity, few refrigerators, and even fewer vehicles. In 2013, less than 1.5% of rural females had electricity and refrigerators. Although urban Liberians had more assets than their rural sisters, still few assets were available to Liberians. For example, urban Ghana and Senegal reached almost 90% of their residents with electricity, while urban Liberia supplied only 18% of its residents. Remarkable progress was rural Ghana. Between 2008 and 2014, the rate of access to electricity increased from 37% to 61%.

Another distinction was evident. Reasonably, televisions, refrigerators, and vehicles are urban because urbanites possessed twice to triple more than rural residents. Other items—radios, bicycles, and motorcycles—were rural assets. Table 4.4 shows the number of these assets by residence. Liberians owned the least among the three countries. Urban dwellers, on average, had one more asset than rural residents had.

In Ghana and Senegal, the disparity between urban-and-rural exists but gets smaller each year. About 65 percent of rural residents held one to three assets. In urban areas, fewer than 50 percent of females possessed four to five resources. In common, fewer than six percent of urban dwellers obtained six to seven, according to the latest DHS results.

IPV was defined as the frequency husbands harmed wives; five reasons in the survey. Husbands abused their wives when wives went outside without telling husbands, neglected children, tried to argue with husbands, refused sex with husbands, and burned food. If female respondents marked all reasons as “yes,” the indicator would show five. Zero was the opposite situation in which husbands did not harm their wives. Table 4.5 displays differences among countries and by residence.

Table 4.1 BMI Quintiles of Women, by Residence

		Rural				Urban			
		Underweight	Normal	Overweight	Obese	Underweight	Normal	Overweight	Obese
Ghana	2003	11.44	72.07	12.95	3.54	6.3	57.71	23.18	12.81
Ghana	2008	10.40	68.62	16.38	4.6	5.7	52.92	27.09	14.29
Ghana	2014	6.83	62.97	21.57	8.63	4.97	44.41	28.98	21.64
Liberia	2007	11.3	75.15	10.35	3.27	8.58	65.82	18.19	7.41
Liberia	2013	9.9	71.74	7.4	10.97	8.35	66.17	7.83	17.65
Senegal	2005	17.08	67.76	11.73	3.43	17.37	53.25	18.2	11.18
Senegal	2010-11	23.91	61.87	11.28	2.94	17.31	53.15	20.13	9.41

Note. Senegal 2012-13, 2014, 2015, and 2016 DHS do not have BMI information.

Table 4.2 Wealth by Residence

		Rural					Urban				
		Poorest	Poorer	Middle	Richer	Richest	Poorest	Poorer	Middle	Richer	Richest
Ghana	2003	32.02	29.86	23.96	10.09	4.07	1.08	2.62	13.34	34.43	48.52
Ghana	2008	30.18	31.22	22	12.41	4.19	0.79	4.58	17.7	33.75	43.17
Ghana	2014	31.37	31.32	24.28	11.87	1.16	2.94	5.45	17.47	31.71	42.43
Liberia	2007	29.96	30.1	23.66	12.09	4.18	0.82	3.34	13.01	36.2	46.63
Liberia	2013	38.42	34.14	19.91	5.44	2.08	3.47	6.98	18.84	32.86	37.85
Senegal	2005	32.07	31.48	22.51	9.13	4.81	0.46	2.93	16.22	34.72	45.67
Senegal	2010-11	31.06	30.31	21.8	10.61	6.22	1.5	5.12	17.85	34.25	41.29
Senegal	2012-13	29.45	29.24	24.34	12.67	4.29	0.97	4.24	14.96	33.53	46.29
Senegal	2014	33.67	29.6	22.81	7.69	6.22	1.65	6.72	17.31	32.61	41.7
Senegal	2015	30.81	29.86	23.33	11.61	4.4	1.84	4.55	16	32.02	45.59
Senegal	2016	31.85	29.71	22.08	9.93	6.42	0.86	6.01	17.3	35.46	40.37

Table 4.3 Full-autonomy Asset Possessions by Residence

		Rural							Urban						
		Electricity	Radio	TV	Fridge	Bicycle	Motorcycle	Vehicle	Electricity	Radio	TV	Fridge	Bicycle	Motorcycle	Vehicle
Ghana	2003	23.25	69.78	11.27	6.89	34.34	2.62	2.86	78.61	77.56	50.95	41.04	15.5	3.9	12.12
Ghana	2008	36.76	69.35	21.39	10.86	37.16	5.77	3.07	84.99	79.21	70.85	48.07	22.36	5.63	14.09
Ghana	2014	61.02	63.61	43.13	18.04	35.06	14.04	4.76	89.22	71.24	79.42	54.08	19.48	7.68	15.73
Liberia	2007	1.12	42.75	1.52	0.91	2.62	0.93	0.26	6.69	72.38	19.07	4.51	7.12	2.31	5.88
Liberia	2013	1.46	51.65	3.17	1.22	1.67	6.6	0.61	18.18	68.51	29.54	7.96	7.39	10.14	8.75
Senegal	2005	21.57	86.03	26.32	8.35	17.39	6.6	6.12	81.06	90.33	73.73	43.5	10.74	9.05	15.9
Senegal	2010-11	33.63	76.09	34.37	8.85	20.36	8.42	3.37	88.78	79.63	84.34	44.48	15.03	12.17	3.2
Senegal	2012-13	31.69	75.4	33.17	8.99	17.99	10.61	1.9	86.54	71.32	83.07	39.27	11.76	15.08	1.81
Senegal	2014	37.62	73.76	36.12	13	16.41	9.21	7.22	84.19	70.97	81.99	38.51	9.89	14.16	11.42
Senegal	2015	37.68	72.44	35.62	11.12	18.72	11.42	6.89	86.11	65.41	81.39	39.51	9.97	9.7	15.44
Senegal	2016	44.01	68.95	40.29	15.5	16.5	12.37	8.11	87.73	68.78	84.41	46.51	10.1	13.52	17.79

Note. Each cell reflects the percentage of female respondents who marked “yes” for each asset. We excluded not de jure residents.

Table 4.4 Number of Full-autonomy Assets by Residence

		Rural							Urban						
		One	Two	Three	Four	Five	Six	Seven	One	Two	Three	Four	Five	Six	Seven
Ghana	2003	36.16	32.28	7.26	4.37	2.05	0.45	0.06	17.08	19.33	17.96	24.47	11.29	2.68	0.48
Ghana	2008	29.52	29.1	13.94	8.43	3.09	1.23	0.11	11.23	12.66	20.31	31.44	14.97	4.32	0.95
Ghana	2014	20.8	24.06	21.99	15.86	7.36	1.65	0.23	7.93	12.28	21.24	32.62	16.47	5.11	0.62
Liberia	2007	40.19	2.58	0.81	0.56	0.05	0.09	0	49.65	15.14	4.99	3.13	2.35	0.1	0
Liberia	2013	46.32	6.26	2.11	0.55	0.09	0	0.04	39.35	16.69	11.97	6.09	2.97	0.64	0.18
Senegal	2005	46.94	20.63	11.5	7.67	3.87	0.6	0.14	9.46	10.17	26.06	32.83	15.07	2.9	0.59
Senegal	2010-11	34.65	19.07	18.13	10.56	3.29	0.56	0.03	5.66	11.7	30.16	35.36	11.1	3.11	0.17
Senegal	2012-13	37.73	17.18	17.99	9.29	3.77	0.71	0.06	7.89	14.67	32	30.31	9.54	2.8	0.07
Senegal	2014	35.2	18.21	19.2	9.67	5.35	0.88	0.19	5.63	13.92	30.79	29.16	13.42	2.51	0.35
Senegal	2015	31.31	17.71	18.85	11.46	4.5	0.68	0.72	5.88	15.57	33.77	25.57	12.66	2.72	0.3
Senegal	2016	29.97	17.19	18.9	12.2	6.39	1.92	0.07	7.06	12.38	25.11	31.48	15.08	4.39	0.5

Note. Above we omitted female respondents with no assets. Ghanaian females in urban areas with zero assets were between 8.05% and 17.37%. In rural Liberia, the range goes up, ranging by year from 44.63 to 55.72%. Rural Senegal was between 11.3 to 14.77%. In urban areas, respondents had more available assets. In Ghana, 3.73 to 6.71% of urban residents marked no assets. Also, only 2.72 to 4% of Senegalese urbanites responded with no full-autonomy assets. However, in urban Liberia, 22.11-24.64% had no assets.

Table 4.5 Percentage Exposed to IPV by Residence

		Rural						Urban					
		None	One	Two	Three	Four	Five	None	One	Two	Three	Four	Five
Ghana	2003	44.83	12.07	11.46	11.78	9.29	10.57	58.31	12.26	8.79	8.67	7.06	4.9
Ghana	2008	55.65	11.66	10.74	10.87	6.29	4.79	71.27	9.81	7.52	5.75	3.39	2.27
Ghana	2014	63.24	9.05	8.33	7.69	5.03	6.67	79.18	7.99	5.3	3.29	2.09	2.16
Liberia	2007	33.96	13.04	15.06	17.35	13.05	7.55	46	10.85	12.52	15.99	6.94	7.7
Liberia	2013	51.49	12.12	10.03	14.59	7.91	3.86	61.8	8.98	7.23	11.98	7.67	2.34
Senegal	2005	26.91	5.91	10.04	12.38	22.83	21.93	43.32	11.04	11.77	10.95	12.04	10.89
Senegal	2010-11	29.47	8.22	8.55	10.16	17.53	26.06	51.2	13.6	10.02	8.49	8.64	8.05
Senegal	2012-13	24.98	8.71	9.95	12.42	25.67	18.28	48.8	12.34	11.17	9.58	11.45	6.66
Senegal	2014	29.82	7.37	7.34	9.57	21.31	24.68	54.22	10.23	7.09	7.77	12.5	8.2
Senegal	2015	31.39	6.42	6.29	9.06	19.98	26.86	57.25	10.42	6.66	6.6	10.14	8.93
Senegal	2016	42.47	5.73	6.25	6.99	17.83	20.72	60.82	8.23	6.35	5.74	9.73	9.13

Note. The percentage table includes intimate partner violence that husbands beat wives for five reasons. Husbands harmed wives when they went outside without telling husbands, neglected children, tried to argue with husbands, refused sex with husbands, and burned food. If female respondents marked all yes, the indicator would show five. None is no IPV case reported.

Over 63% of female respondents in rural Ghana and about 80% of urban Ghanaians reported zero IPV in 2014. That tendency had continued since 2003 in the Ghana DHS, likewise in Liberia. Five of ten rural Liberians had reported no cases, and six of ten urban females were burden free in 2013. In contrast, IPV in Senegal was alarming. In 2015, over 46% of rural women reported four to five instances. The same year, about 20% of urban females experienced similar cases. One year later, the extreme cases were down to 38% in rural areas and about 19% in urban areas, but the proportions were still the highest.

4.6 Methods

The analysis explored additional variables that statistically explain two populations' socioeconomic status in recent history. During the selection stage, we discarded some variables because of a lack of information. For instance, a question in the DHS asked female respondents whether they earn less, about the same, or more than spouses or partners. We did not include this variable because of missing data from Senegalese females. We also noted that Senegalese's BMI information was missing in the latest DHS. Another consideration was participation in literacy programs. We observed a vast literacy gap between urban and rural residents, but too many missing values caused us to select a related variable, *frequency of reading newspaper or magazines* (*Newsmag*). *Newsmag* contains information on infrastructure to empower literacy and a recurrence (i.e., 0 = none, 1 = less than once a week, 2 = at least once a week, 3 = almost every day).

Husbands' (Husedu) and female respondents' education (CatEdu) levels (0 = no education, 1 = primary education, 2 = secondary education, 3 = above secondary-level education) were in the model to describe household wealth statistically.

Household wealth (0 = poorest, 1 = poorer, 2 = middle, 3 = richer, 4 = richest) was used to characterize women's nutrition gap and was explained by sociodemographic, community, and socioeconomic variables. It was questionable whether the number of autonomy assets as an independent variable could predict wealth, and we examined Kendall's tau-b correlations. There was a positive, proportional, and moderate correlation between assets and wealth $\left(T_b = (0.462, 0.564),\ p = (0.004, 0.006)\right)$. Note that each parenthesis shows the range of all data, and the comma divides the data into low and high values. We discern chosen assets are part of wealth, but repeatedly, they are essential for females to be autonomous.

Numofchil represents the number of children under five-years-old in the family. We hypothesized that fewer socioeconomic opportunities might exist for a woman who raises more infants or young children.

Another demographic predictor, *Age* combined with the residence, *UR*. *AgeUR* signifies an interaction term that accommodates age information from 15 to 49 and simultaneously those respondents' residence, either urban or rural. *UR* was a dichotomous variable; *0* represented *rural* and *1* designated *urban* resident.

We acknowledged two community variables – the time to get to the nearest water source (timewater) and religion. With inclusion, we tried to understand the opportunity cost of fetching water to socio-economic activities. *Religion* was a categorical, nominal variable (i.e., 0 = no religion, 1 = traditional/animism, 2 = Christian, 3 = Islam). We postulated that a female's religious affiliation influenced her life decisions.

We first processed univariate regressions to determine dependent and independent variables. Then we performed multiple stepwise regressions to choose explanatory variables statistically and another purposeful selection for logical variable choice.

Identification of BMI alongside selected predictors was an antecedent analysis. BMI was a function of wealth, AgeUR, numofchil, newsmag, husedu, and IPV. Then we predicted wealth with existing and the other new explanatory variables. Because BMI and wealth were ordinal, ordered logit models were appropriate. We also traced discrete changes.

Multiple imputations on missing data were necessary to complete the study. We visually checked patterns of missing data. With Liberia, we decided not to impute missing because data were not missing at random. Statistically, the dependent variable related itself but affected other predictors if imputed. The other two countries had missing values at random. We converted data to the wide style in Stata 14.2 to efficiently match, correlate, and compare the imputed to existing information. The biggest imputations were a variable of *timewater*: in 2008 Ghana DHS, 1,114 imputed values were out of 4,916 observations. All other ascribed percentages of imputed values were about five percent or less. We implemented the ordinal logit models again for Ghana and Senegal.

4.7 Results

Despite incomplete information, we found evidence of influencers of BMI. Primarily, wealth escalated the odds ratios of BMI. We substantiated the most significant odds were 5.82 in the wealthiest group in the 2014 Ghana DHS. An interpretation is that a female in the most affluent category is 5.82 times more likely to have a higher BMI than is another in the most deprived group. AgeUR as well increased the odds-ratio range of BMI between 1.02 and 1.04 throughout all three countries. This interval provides a reasonable claim that a female who lives in an urban area has the odds of a higher BMI 1.02 and 1.04 times than a woman who is one year younger and resides in a rural area.

Conjointly, we detected a factor unfavorable to BMI. IPV affected BMI negatively in all settings. The lowest odds ratio was 0.51 for Ghanaian respondents with exposure to family violence in four different situations. It was describable that a female in the group has merely 0.51 times higher odds than another woman with no instances of IPV. Not only Ghana but Senegal showed a substantial, negative relationship of IPV to BMI. We could reject the null hypothesis at the 0.05 test level (In most cases, we rejected at 0.01 alpha level.) and claim wealth, AgeUR, and IPV influenced positively or negatively females' BMI levels. But we did not find statistical associations of BMI with education, literacy levels, or husband's education.

Tables 4.6 to 4.8 show the results of other ordered logit models with wealth as the common dependent variable. Due to various years of study data, we put minimum and maximum outputs in parentheses. We included all results per country for two reasons. First, one merged table is more readable and interpretable than six separate Senegal tables, for example. Second, we could better compare factors consistently and explore the most influential variable on wealth. We included 12 cutpoints (four points per table) to identify ordinal predictability between wealth and its explanatory variables.

We begin interpretations of positive independent factors predicting wealth. The number of selected autonomy assets increased the odds ratios of wealth most significantly. But twenty-seven million in the 2003 Ghana DHS and other considerable odds in 2007 and 2013 Liberia DHS were irrational. The results can misguide interpretations, regardless of the statistical significance. Two reasons follow. Number one, almost none of Liberians had seven assets, and few had five to six assets. Ghanaians' standard of living was better than Liberians and identified few observations for owned assets in the 2008 data. Number two, we observed multicollinearity between wealth and assets. We tested separate multiple regressions with wealth scores in DHS.

The number of assets increased R-squares to a range between 0.4 and 0.6, but we found no critical evidence of multicollinearity. Overall, we found that the more autonomy assets allowed to a female, proportionally, the higher wealth will be, based on the odds ratios.

Education was the second most crucial factor in causing increased wealth. It was logical that developing human capital could be the most significant factor to raise wealth without the certainty of the assets-and-wealth association. Some Ghanaians who finished post-secondary education had 10.47 odds, compared to those without schooling. We monitored two odds ratios less than one to Senegalese groups in completing primary and secondary schools in the 2015 Senegal DHS. Other than this unpredictable case, we identified all educational levels were positively related to the level of wealth.

Together, husbands' education improved wealth. The husbands with primary education had odds higher than other husbands without schooling, although we found no difference in the Liberia DHS. Secondary and post-secondary education always expanded the odds of wealth gradually. At the 0.001 significance (alpha level), we reject the null hypotheses of no differences between wealth levels based on education levels.

The periodicity of reading newspapers or magazines (newsmag) was positive and robust statistically to a standard of living. In Ghana, Liberia, and Senegal, newsmag increases the opportunity to learn about social issues and benefits literacy and have odds more than increasing wealth. In Senegal, the odds were 1.1 up to 4.8 for those reading newspapers or magazines at least once a week. Our interpretation is that a way to empower literacy opens more favorable circumstances than for others who do not have that empowerment.

Our interaction variable, ageUR, was another incremental factor of wealth. Coherently, Ghanaians, Liberians, and Senegalese 16 years of age in urban residence had 1.05 to 1.08 of the odds ratios, compared to ones who are a year younger in rural areas. We are statistically confident that a socio-demographic and urban factor together can benefit wealth and material comfort.

We identified two predictors detrimental to wealth. The numbers of children under five years old in households come first. Mothers in all three countries with one or more children had an odds ratio range for wealth at 0.75 to 0.97 compared to others without a child. We noticed the effect was most disadvantageous to Ghanaian females for more and better social chances. Those who face social constraints should pay relatively a higher opportunity cost to raise an additional child (A logic behind – We observed many more Ghanaian respondents *earned more or about the same income as their husbands* compared to Liberians and Senegalese.).

We left unexplored a possibility that Ghanaian females who spent extended time fetching water could have a lower odds ratio of acquiring wealth than those who spent less time.

Intimate partner violence (IPV) was another but more severe obstacle to higher wealth for Senegalese women. Those who marked all five reasons to get hurt had the odds of being a higher wealth of only 0.35 to 0.64 times than those experiencing no IPV.

The last category, religion, revealed mixed results. Over 80 percent of Ghanaian females were Christians, based on the DHS datasets. A Ghanaian woman in the Christian community had 1.24 to 1.62 times higher odds of wealth than others not having any religion.

Odds ratios ranging from 0.85 to 8.83 were too inconsistent to conclude Islam's influence (the predominant religion) on wealth in Senegal. One unexpected result was Liberians in the Islamic community had 1.59 to 4.87 times odds higher than non-religious Liberians. The odds were larger than Liberian Christian women, which differed from the 1986 Liberia DHS report. We need further information to investigate trends since the end of the civil war.

Table 4.6 Ghana: Estimated Regression for Wealth, Multiple Imputation

Variables	Categories	Odds Ratios	Standard Errors	Wald Chi-Sq.	Pr > Chi-Sq.
Age*UR	Interaction	(1.06,1.08)	(0.003,0.006)	(13.7,21.17)	<0.001
Numofchil	Continuous	(0.75,0.81)	(0.037,0.052)	(-6.65, -5.27)	<0.001
Religion[a]	Traditional	(0.41,0.6)	(0.276,0.343)	(-2.94, -1.84)	(0.003,0.067)
	Christian	(1.24,1.62)	(0.179,0.251)	(1.04,2.12)	(0.035,0.301)
	Muslim	(0.8,1.45)	(0.21,0.293)	(-0.89,1.78)	(0.076,0.768)
Husedu[b]	Primary	(1.6,1.99)	(0.136,0.166)	(3.08,4.13)	(<0.001,0.002)
	Secondary	(2.81,3.56)	(0.125,0.147)	(7.78,10.17)	<0.001
	Higher	(2.48,6.11)	(0.164,0.222)	(4.4,11.05)	<0.001
Newsmag[c]	Less than once/week	(1.6,1.75)	(0.148,0.221)	(2.53,3.19)	(0.002,0.012)
	At least once/week	(1.16,3)	(0.156,0.262)	(0.65,4.2)	(<0.001,0.518)
	Almost every day*	(1.49,2.58)	(0.42,0.507)	(0.95,1.87)	(0.063,0.345)
Assets[d]	1	(1.39,3.32)	(0.126,0.158)	(2.06,7.94)	(<0.001,0.04)
	2	(2.23,3.13)	(0.147,0.176)	(4.77,7.75)	<0.001
	3	(6.17,24.47)	(0.167,0.212)	(10.9,16.31)	<0.001
	4	(17.86,125.98)	(0.185,0.263)	(15.56,23.5)	<0.001
	5	(22.54,300.2)	(0.21,0.311)	(14.86,18.32)	<0.001
	6	(21.52,579.16)	(0.294,0.867)	(7.34,14.54)	<0.001
	7	(18.15,27 million)	(0.387,6.23)	(2.75,7.49)	(<0.001,0.113)
CatEdu[e]	Primary	(1.73,2.21)	(0.097,0.135)	(5.3,5.9)	<0.001
	Secondary	(2.11,3.33)	(0.105,0.122)	(6.95,11.47)	<0.001
	Higher	(2.56,10.47)	(0.211,0.709)	(1.33,11.12)	(<0.001,0.186)
IPV[f]	1	(0.84,1.00)	(0.111,0.151)	(-1.53, -0.03)	0.127
	2	(0.58,0.94)	(0.146,0.155)	(-3.47, -0.39)	0.001
	3	(0.57,0.67)	(0.148,0.161)	(-3.74, -2.49)	<0.001
	4	(0.6,0.67)	(0.194,0.197)	(-2.56, -2.06)	0.011
	5	(0.46,1.56)	(0.209,0.223)	(-3.51, -2.14)	<0.001
Timewater	Continuous	(0.98,0.99)	0.003	(-8.78, -2.66)	<0.001
Intercept	Cut 1	(2.17,3.45)	(0.219,0.3)	(2.86,5.66)	(<0.001,0.005)
	Cut 2	(16.18,26.89)	(0.238,0.31)	(10.29,12.03)	<0.001
	Cut 3	(123.3,240.23)	(0.263,0.326)	(16.83,18.29)	<0.001
	Cut 4	(1290.95,4750.65)	(0.29,0.35)	(23.91,26.2)	<0.001

Source: Analysis based on the 2003, 2008, and 2014 Ghana DHS data.

Note. n = 5,691 (2003), 3,197 (2008), and 6,225 (2014). Adjusted Wald test for all parameters: F (21,192) = 136.32, F (27,386) = 53.68, and F (26,402) = 90.3. All $p < 0.001$. Wald tests are for measuring the overall covariate effects of all estimated odds ratios. The null hypothesis indicates all selected explanatory variables are not statistically significant. Or the alternative hypothesis

could be correct if the chosen variables make a statistical difference to wealth. In Stata, F-statistics equal to the results of multi-parameter Wald tests.
[a] Referent category: No religion
[b] Referent category: No education
[c] Referent category: Not available
[d] Referent category: No assets available
[e] Referent category: No education
[f] Referent category: No intimate partner violence
Referent categories were the same in Table 4.7 and Table 4.8.

Table 4.7 Liberia: Estimated Regression for Wealth

Variables	Categories	Odds Ratios	Standard Errors	Wald Chi-Sq.	Pr > Chi-Sq.
Age*UR	Interaction	(1.075,1.08)	(0.005,0.006)	(13.32,16.61)	<0.001
Numofchil	Continuous	(0.89,0.96)	0.032	(-3.06, -1.14)	(0.002,0.256)
Religion[a]	Traditional	(0.18,1.74)	(0.119,0.6)	(-2.6,1.61)	(0.01,0.108)
	Christian	(0.89,2.17)	(0.17,0.561)	(-0.6,3)	(0.003,0.548)
	Muslim	(1.59,4.87)	(0.393,1.466)	(1.87,5.26)	(<0.001,0.063)
Husedu[b]	Primary	(0.96,1.1)	(0.1,0.121)	(-0.42,0.85)	(0.394,0.675)
	Secondary	(1.54,1.63)	(0.168,0.205)	(3.27,4.78)	<0.001
	Higher	(3.03,3.07)	(0.574,0.679)	(5.06,5.83)	<0.001
Newsmag[c]	Less than once/week	(1.38,1.73)	(0.252,0.299)	(1.49,3.75)	(<0.001,0.14)
	At least once/week	(1.52,2.05)	(0.245,0.427)	(2.6,3.45)	(0.001,0.01)
	Almost every day*	1.75	0.439	2.24	0.027
Assets[d]	1	(3.1,4.79)	(0.275,0.447)	(12.72,16.76)	<0.001
	2	(19.41,28.73)	(3.77,6.396)	(15.09,15.27)	<0.001
	3	(161.68,577.66)	(37.516,405.543)	(9.06,21.92)	<0.001
	4	(346.29,722.43)	(165.663,628.685)	(7.56,12.22)	<0.001
	5	(244 million, 1.09 billion)	(137 million, 575 million)	(34.34,39.28)	<0.001
	6	(483 million, 1.57 billion)	(240 million, 1.61 billion)	(20.76,40.13)	<0.001
	7	3.45 billion	3.55 billion	21.33	(<0.001,0.3)

Table 4.7 Continued

Variables	Categories	Odds Ratios	Standard Errors	Wald Chi-Sq.	Pr > Chi-Sq.
CatEdu[e]	Primary	(1.39,1.54)	(0.143,0.184)	(3.16,3.65)	(<0.001,0.002)
	Secondary	(2.1,2.84)	(0.331,0.37)	(4.7,7.98)	<0.001
	Higher	(3.93,6.84)	(1.091,4.791)	(2.75,4.93)	(<0.001,0.007)
Intercept	Cut 1	(0.03,1.38)	(0.201,0.293)	(0.13,4.72)	(<0.001,0.896)
	Cut 2	(1.61,3.04)	(0.22,0.28)	(7.32,10.85)	<0.001
	Cut 3	(3.21,4.77)	(0.217,0.298)	(14.84,16.01)	<0.001
	Cut 4	(5.6,7.28)	(0.228,0.327)	(22.3,24.59)	<0.001

Source: Analysis based on the 2007 and 2013 Liberia DHS data.

Note. n = 4,749 (2007) and 6,491 (2013). Adjusted Wald test for all parameters: F (20,135) = 119.03 and F (20,273) = 204.88. All $p < 0.001$.

Table 4.8 Senegal: Estimated Regression for Wealth, Multiple Imputation

Variables	Categories	Odds Ratios	Standard Errors	Wald Chi-Sq.	Pr > Chi-Sq.
Age*UR	Interaction	(1.05,1.06)	(0.005,0.007)	(9.09,10.94)	<0.001
Numofchil	Continuous	(0.89,0.97)	(0.021,0.038)	(-4.85, -1.34)	(<0.001,0.182)
Religion[a]	Christian	(0.74,6.66)	(0.321,0.681)	(0.6,3.85)	(<0.001,0.689)
	Muslim	(0.85,8.83)	(0.264,0.646)	(-0.36,5.17)	(<0.001,0.722)
Husedu[b]	Primary	(1.1,1.41)	(0.103,0.183)	(0.54,2.51)	(0.013,0.588)
	Secondary	(1.18,1.99)	(0.114,0.213)	(1.25,3.69)	<0.001
	Higher	(1.85,3.78)	(0.161,0.314)	(2.37,5.48)	(<0.001,0.019)
Newsmag[c]	Less than once/week	(1.18,1.65)	(0.121,0.251)	(1.16,2.7)	(0.008,0.249)
	At least once/week	(1.1,4.8)	(0.153,0.286)	(0.64,5.57)	(<0.001,0.52)
	Almost every day*	1.16	0.371	0.4	0.691
Assets[d]	1	(0.94,1.63)	(0.11,0.156)	(-0.43,4.46)	(<0.001,0.694)
	2	(1.56,5.04)	(0.149,0.201)	(2.55,10.87)	(<0.001,0.011)
	3	(10.65,33.29)	(0.151,0.237)	(11.75,23.28)	<0.001
	4	(22.57,122.78)	(0.182,0.279)	(12.08,25.9)	<0.001

Table 4.8 Continued

Variables	Categories	Odds Ratios	Standard Errors	Wald Chi-Sq.	Pr > Chi-Sq.
Assets[d]	5	(27.93,156.39)	(0.243,0.511)	(8.79,20.82)	<0.001
	6	(28.85,118.15)	(0.417,0.698)	(5.04,11.27)	<0.001
	7	(15.25,528.43)	(0.779,2.576)	(1.06,7.12)	(<0.001,0.292)
CatEdu[e]	Primary	(0.92,1.65)	(0.08,0.102)	(-0.84,6.22)	(<0.001,0.403)
	Secondary	(0.77,2.41)	(0.136,0.199)	(-1.66,6.24)	(<0.001,0.22)
	Higher	(1.37,4.16)	(0.389,0.785)	(0.68,3.44)	(0.001,0.496)
IPV[f]	1	(0.65,0.99)	(0.08,0.178)	(-3.49, -0.08)	(0.001,0.938)
	2	(0.56,0.78)	(0.101,0.158)	(-4.99, -1.82)	(<0.001,0.069)
	3	(0.49,0.99)	(0.006,0.154)	(-5.88, -0.09)	(<0.001,0.928)
	4	(0.5,0.79)	(0.094,0.14)	(-6.94, -1.95)	(<0.001,0.052)
	5	(0.35,0.64)	(0.095,0.141)	(-8.38, -3.63)	<0.001
Intercept	Cut 1	(0.43,4.43)	(0.286,0.677)	(-1.8,3.56)	(<0.001,0.755)
	Cut 2	(2.18,26.38)	(0.285,0.648)	(1.69,10.2)	(<0.001,0.091)
	Cut 3	(16.96,180.28)	(0.301,0.669)	(5.9,16.24)	<0.001
	Cut 4	(197.75,1446.12)	(0.317,0.681)	(10.34,22.2)	<0.001

Source: Analysis based on the 2005, 2010-11, 2012-13, 2014, 2015, and 2016 Senegal DHS data.

Note. n = 9,783 (2005), 10,677 (2010-11), 5,511 (2012-13), 5,592 (2014), 5,755 (2015), and 5,889 (2016). Adjusted Wald test for all parameters on each year: F (25,369) = 72.62, F (24,357) = 91.73, F (24,170) = 49.66, F (24,149) = 77.55, F (24,183) = 65.66, and F (24,182) = 67.79. All $p < 0.001$.

In Tables 4.9 and 4.10, we reported the marginal effects. Higher exposure to IPV whose husbands or partners abused recorded much lower wealth. In Senegal, those females who experienced all IPV cases were 5.8 to 11.1 percentage points more likely to be in the most deprived group and 5.9 and 5.1 percentage points less likely to be in the richest category. The relationship between IPV and wealth was similar to Ghana.

Table 4.9 IPV and Wealth: Average Marginal Effects in Percent

Countries	Selected Variable	Wealth				
	IPV	Poorest	Poorer	Middle	Richer	Richest
Senegal	1	(0.2, 3.9)	(0, 0.5)	(-0.4, 0)	(-1, 0)	(-3, -0.1)
	2	(2.7, 6)	(0, 0.8)	(-1, -0.1)	(-1, -0.3)	(-4.7, -1.8)
	3	(0.5, 6.9)	(0, 0.8)	(-0.9, -0.1)	(-1.9, -0.1)	(-5.5, -2.9)
	4	(8.1, 3.5)	(0, 0.8)	(-1.2, -0.3)	(-1.9, -0.4)	(-5.9, -5.1)
	5	(5.8, 11.1)	(-0.3, 0.9)	(-1.7, -0.4)	(-3.1, -0.6)	(-8.2, -5)
Ghana	1	(-0.4, 0.6)	(-0.1, 0.2)	(0, 0.1)	(-0.1, 0.1)	(-0.6, 0.2)
	2	(0.1, 4.8)	(0, 1)	(-0.1, 0)	(-1.1, 0)	(-4.5, 0)
	3	(3.4, 5.4)	(0.3, 1)	(-1.2, -0.1)	(-1.3, -1.1)	(-5.1, -1.5)
	4	(3.3, 3.9)	(0.3, 0.8)	(-1.1, -0.1)	(-1, -0.9)	(-3.8, -1.5)
	5	(2.8, 5.7)	(0.3, 1.1)	(-0.2, -0.1)	(-1.3, -0.9)	(-5.3, -1.3)

Table 4.10 Education and Wealth: Average Marginal Effects in Percent

Countries	Selected Variable	Wealth				
	Education	Poorest	Poorer	Middle	Richer	Richest
Senegal	Primary	(-5.6, 0.6)	(-0.3, 0)	(0, 1.9)	(-0.1, 0.6)	(-0.4, 3.4)
	Secondary	(-9.1, -1.6)	(-1.4, 0)	(-0.2, 3.3)	(-0.7, 1.2)	(1.3, 6)
	Post-Secondary	(-15.1, -7.5)	(-5.5, -1.4)	(0.2, 3.3)	(0.4, 2.2)	(6, 18.2)
Ghana	Primary	(-9, -5.4)	(-1, -0.1)	(0.4, 3)	(1.6, 2.7)	(3.1, 4.4)
	Secondary	(-12, -8.4)	(-2.7, -0.9)	(0.5, 4.3)	(2.3, 3.7)	(4.3, 9.3)
	Post-Secondary	(-16.8, -11.3)	(-7.2, -1.2)	(-0.5, 4.7)	(3.5, 4.3)	(5.3, 20.2)
Liberia	Primary	(-5.4, -3.7)	(-0.9, -0.6)	(0.6, 1.4)	(1.8, 2.2)	(1.8, 2.7)
	Secondary	(-10.5, -8.7)	(-3, -2.1)	(1.3, 2.2)	(3.7, 5.6)	(4.9, 6.6)
	Post-Secondary	(-17.5, -13)	(-9.4, -4.6)	(1.3, 2.2)	(7.2, 10)	(9.1, 14.8)

We observed an opposite, substantive effect, as shown in Table 4.10. Females in the three countries scored higher for wealth when they were more educated. The marginal effects, on average, appear Senegalese, Ghanaian, and Liberians who completed post-secondary education were six to around 18, about five to 20, and approximate nine to 15 percentage points more likely in the wealthiest class, respectively. In another interpretation, those highly educated were 7.5 to 17.5 percentage points less likely to be the poorest. Thus, we are confident that primary education achievers—compared to those without schooling—are more frequently seen in more prosperous groups and less often found in disadvantaged groups.

4.8 Conclusions

Urbanization causes persistent, multifaceted inequalities. While many females in the city can pursue and achieve their own goals, daughters and young mothers in rural areas face knottier problems of isolation, abandonment, and often abuse. To realize actual development, females must be decision-makers. Recognizing this situation in West Africa is of paramount importance to prepare women to be equally identified, treated, and educated as men with tailored socioeconomic and sociodemographic policy.

CHAPTER V

CONCLUSIONS

This chapter summarized three studies and their relationship. The comprehensive study examined the significant challenges of rural Ghana, Liberia, and Senegal. In Chapter II, we delved into agricultural production and household food security. Outside and family labor unitedly increase crop yield, but their roles and responsibilities differ. Amid incomplete substitution for mechanization and technologies, labor power is essential. Even if rural transformation is achieved, sons and daughters should reside in rural communities to prevail over the future of farming. Agriculture should be a business and grow in competitiveness to other activities more than simply allowing survival. Borne in mind every point, we applied Chi-square Automatic Interaction Detection (CHAID) and Random Forest to organize predictors of household food security. Decision trees as the results embodied financial, non-financial, continuous, dichotomous, and categorical predictors contextually. For Liberia and Senegal, community support in the worst rainy season is vital to severe and moderate food-insecure households. Additional support and tailored agricultural policy should be to female-headed homes to ensue equality to male-headed families.

Several predictors showed where each nation should make an extra effort for tomorrow's farming. In Liberia, land conflict is something to be resolved, as is varied land productivity.

The amount of *Zakat* and *Sadaqah*, respectively, for involuntary and voluntary almsgiving, was proportional to household food security and the quantity of staple crops harvested per household. Together with Taal (1989) and FAO (2016), we highlight the importance of *Zakat* and *Sadaqah* as standards of regional stability and the role of community leadership.

Suppose a scenario of constant population growth and stagnant food production. One more cause, what if rural villages keep losing the youth population? An alternative development option is family planning. Family planning has mainly two roles. Nationally, balanced population growth between urban and rural areas should be. Continentally in sub-Saharan Africa (SSA), family planning means reducing additional unmet needs among teenage girls. That is how we drew attention to the perception of change. Our target population was 15- to 49-year-old married, living with partners, fecund, and pregnant women in Ghana, Liberia, and Senegal Demographic and Health Surveys (DHS).

Chapter III focused on how radio communications as a medium of family planning information and the treatment variable could change their current and future children between zero and 30. After Instrumental Variable (IV) estimations and Coarsened Exact Matching (CEM)-weighted multiple regressions, our findings consistently showed radios as a knowledge domain, contraception as use domain, and no-more child preference reduced the ideal number of children. Our choice of instruments and covariates induced wives/females and husbands/cohabitating partners to pursue family planning together. We recall Soughou et al. (2020) that women's health autonomy and family-planning decisions depend on their partners/husbands. Steadfastly, we hope health and literacy education and more socioeconomic bring women and men as equal.

In Chapter IV, we explored more in the DHS to realize how wives' and husbands' education increases household wealth, our dependent variable. Using ordinal logistic regression of Ghana, Liberia, and Senegal, combined with multiple imputations for missing data, we found coherent results that togetherness of spouses' education increased odds of the dependent variable. Conforming with our findings in Chapter III, more children five years and below decreased the likelihood of wealth.

We performed the average marginal effects of intimate partner violence (IPV) and education on wealth in detail. The former decreased household wealth as IPV case up; the latter increased as education level increased.

After our comprehensive study, we hardly believe the future to be sustainable. We must realize and confront the challenges and then bring options for tomorrow. That is how we directed attention toward agricultural production and household food security, family planning, and female empowerment in Ghana, Liberia, and Senegal.

Let us forget the rosy future. Rural villagers face dual challenges to feed the nation and themselves. Stood on our ex-ante study, more community and policy support should occur so that farming gains competitiveness. If agricultural productivity increases in a short period, we should consider an alternative: family planning. We observed that radio communications could help family planning. Our recommendation of the bottom-up approach is to gather concerns and questions from more homemakers, female farmers, and others working outside houses who are illiterate, communicate in local dialects, and are familiar with indigenous cultures could get covered by local radio stations. Radio stations couple with ICTs, including computers, smartphone devices, and other electric equipment, to deliver up-to-date, accurate information and answer family planning questions. Over time, we should focus on empowering women. Education enhances human and socioeconomic capital through a collaborative decision-making process between wives and husbands or cohabitating partners.

Our concluding remark: fear not the challenges, face reality and provide science-based options for tomorrow's humanity.

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APPENDIX

Chapter II

Figure A.1 Land Conflict and Drought/Flood in Ghana

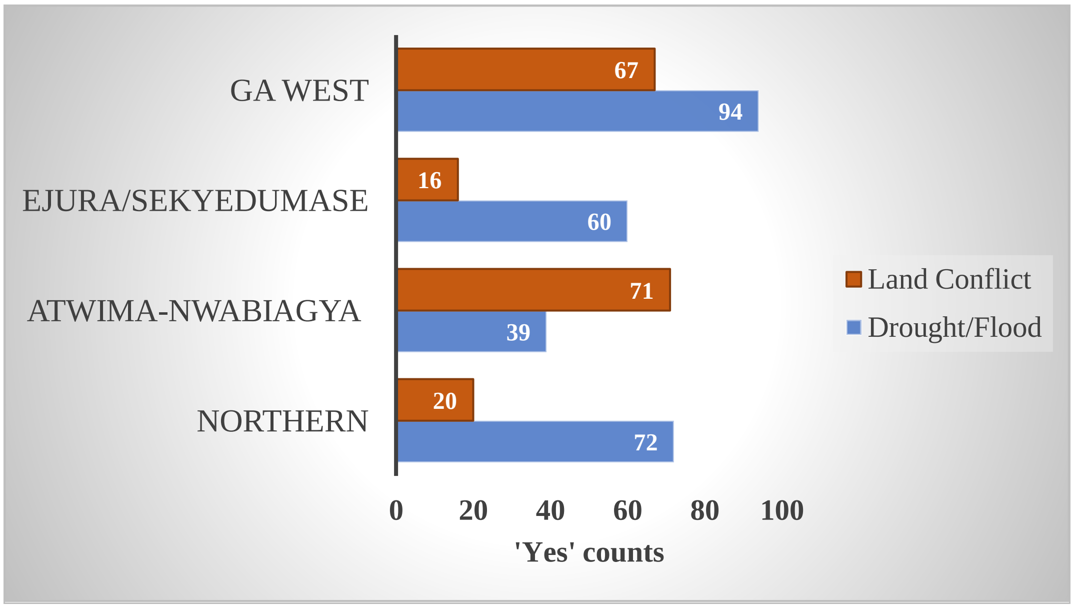


Figure A.2 Land Conflict by Land Conversion (Swamps) in Liberia

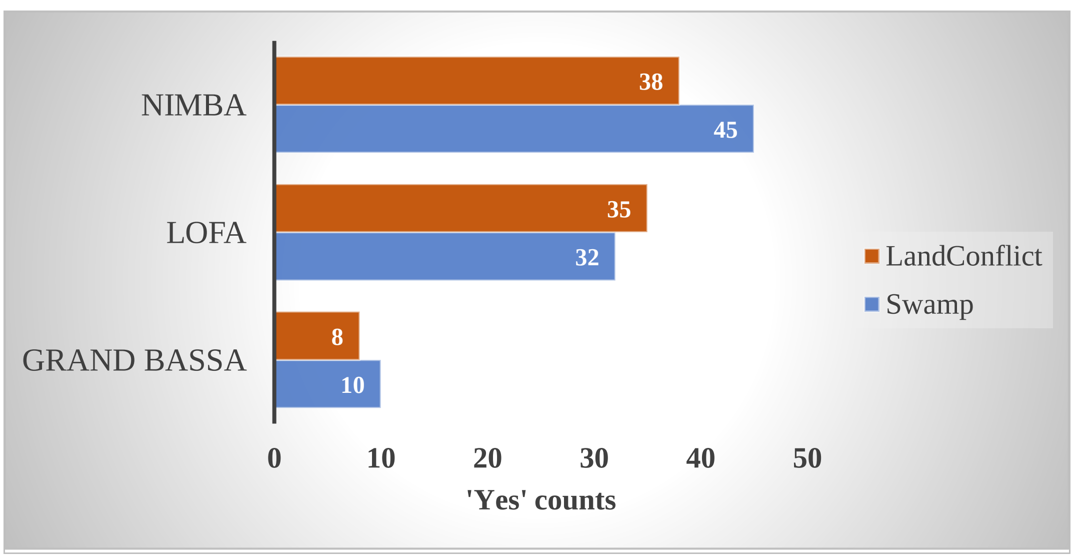


Figure A.3 Ghana's Stacked Information on Exogenous Assistance, Agriculture-related Information and Selling Channel

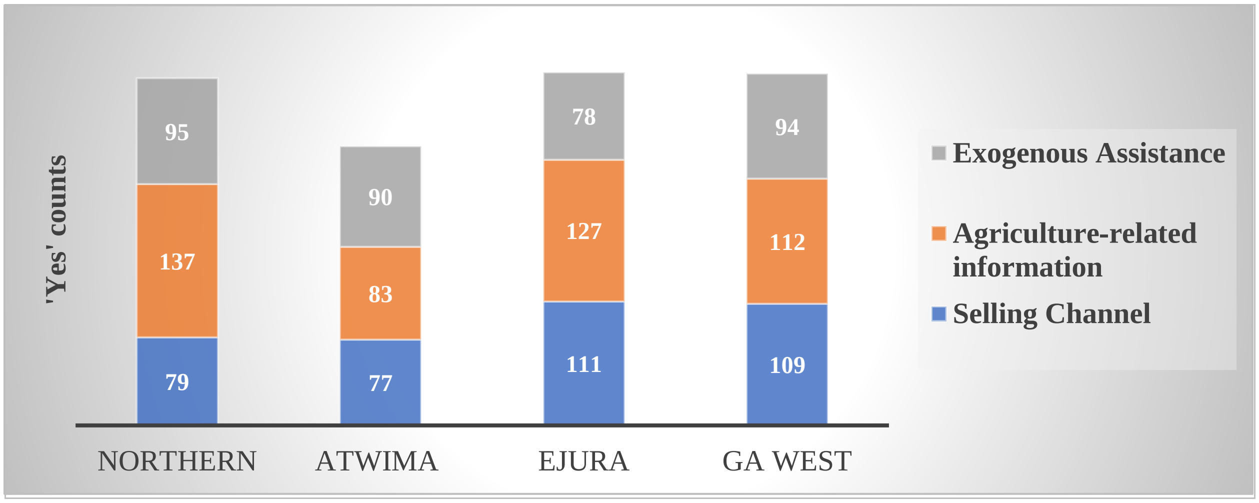


Figure A.4 Liberia's Stacked Information on Exogenous Assistance, Agriculture-related Information and Selling Channel

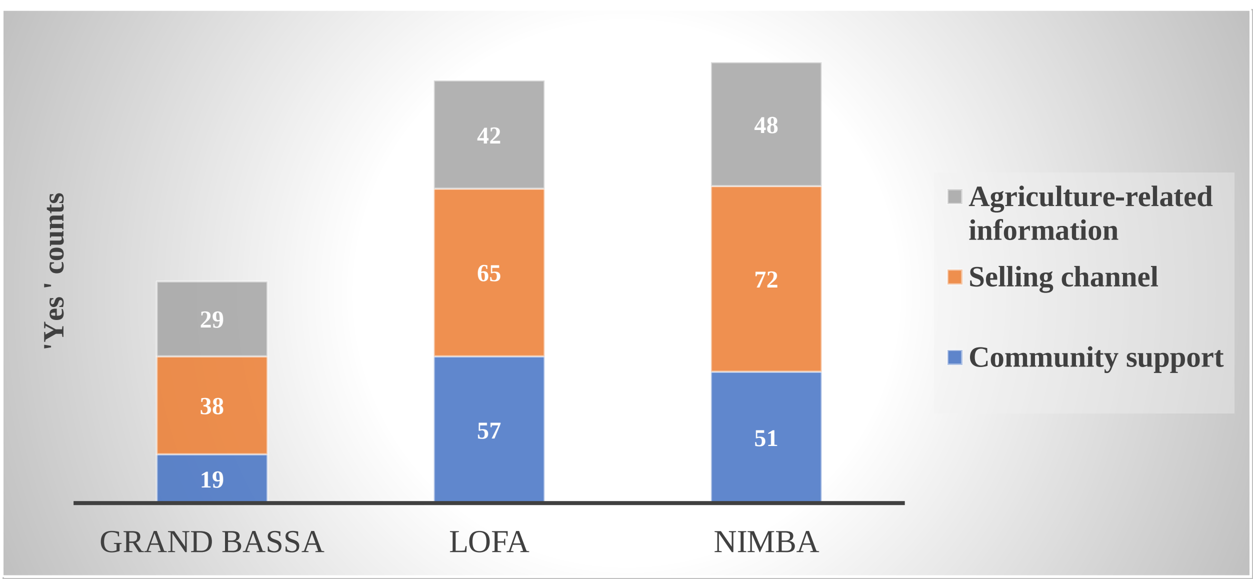


Figure A.5 Senegal's Stacked Information on Selling Location and Community Support

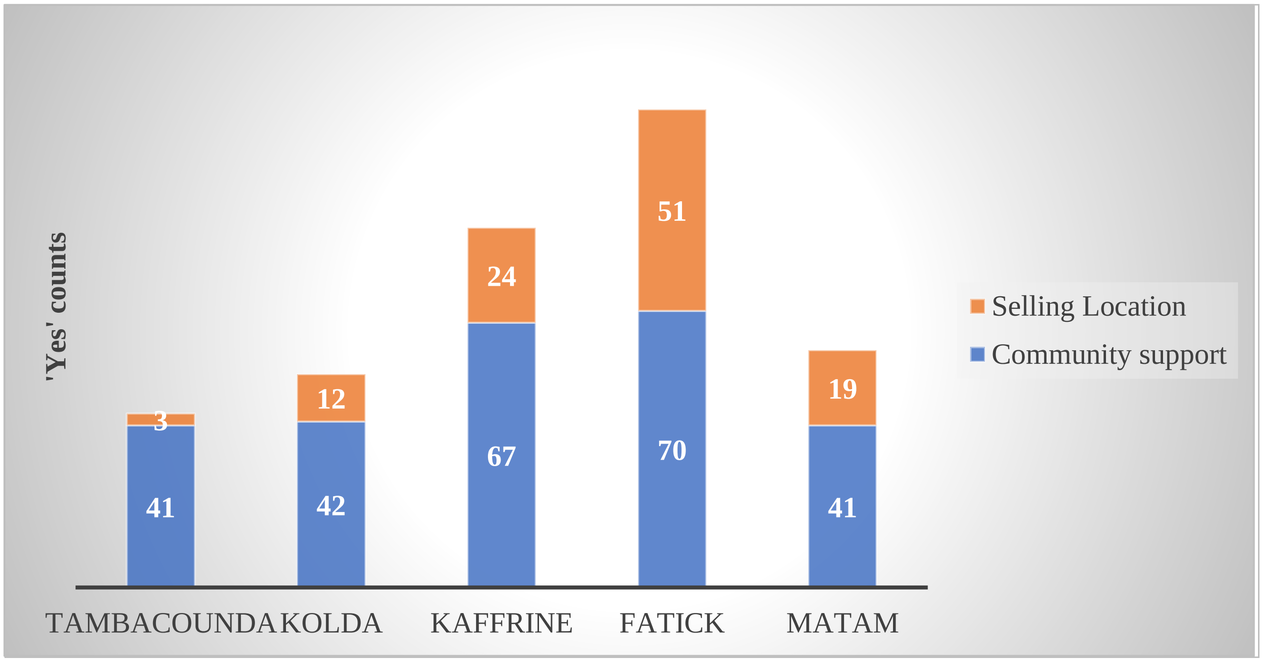


Figure A.6 (Ghana) Boxplot of crop, Off-farm, and Animal Income

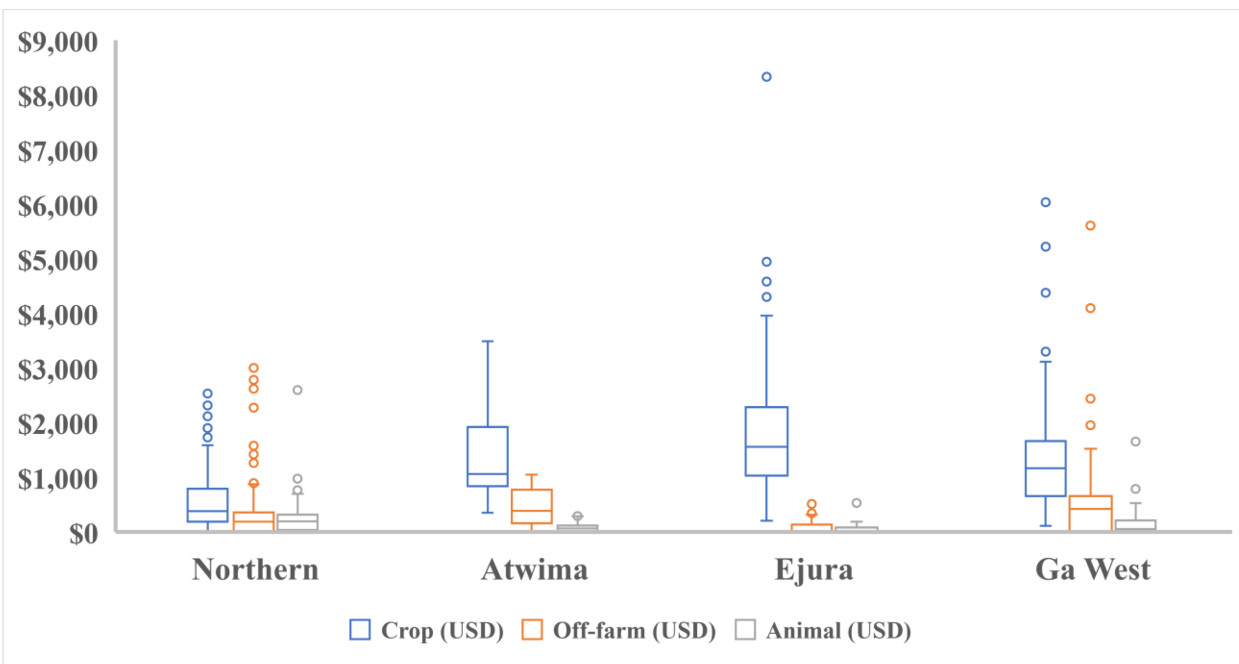


Figure A.7 (Liberia) Boxplot of Crop and Off-farm Income

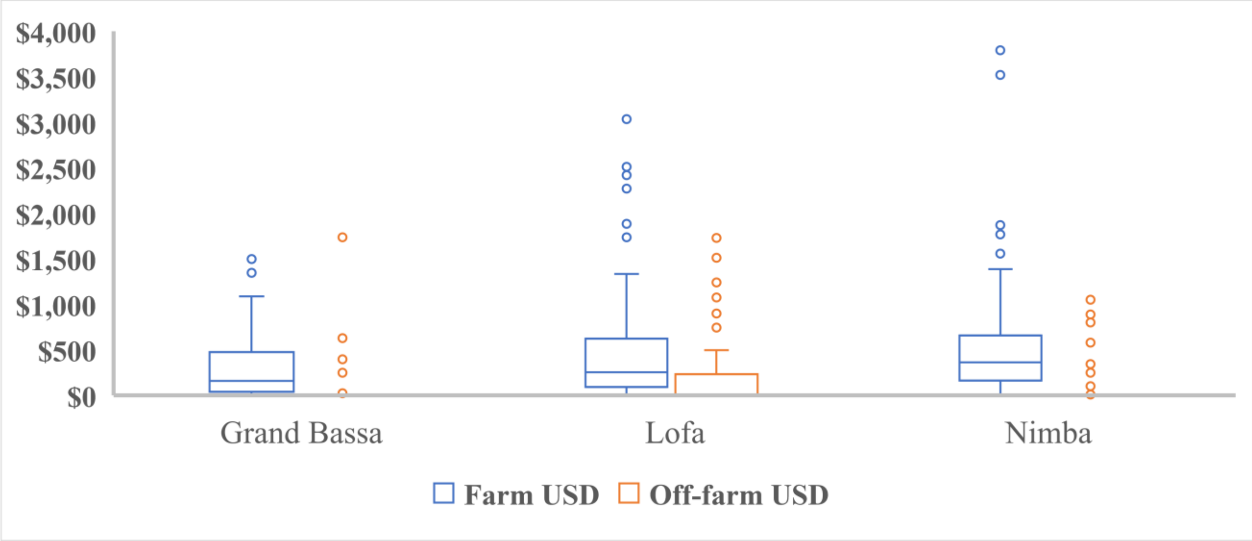


Figure A.8 (Senegal) Boxplot of Crop, Off-farm, and Animal Income

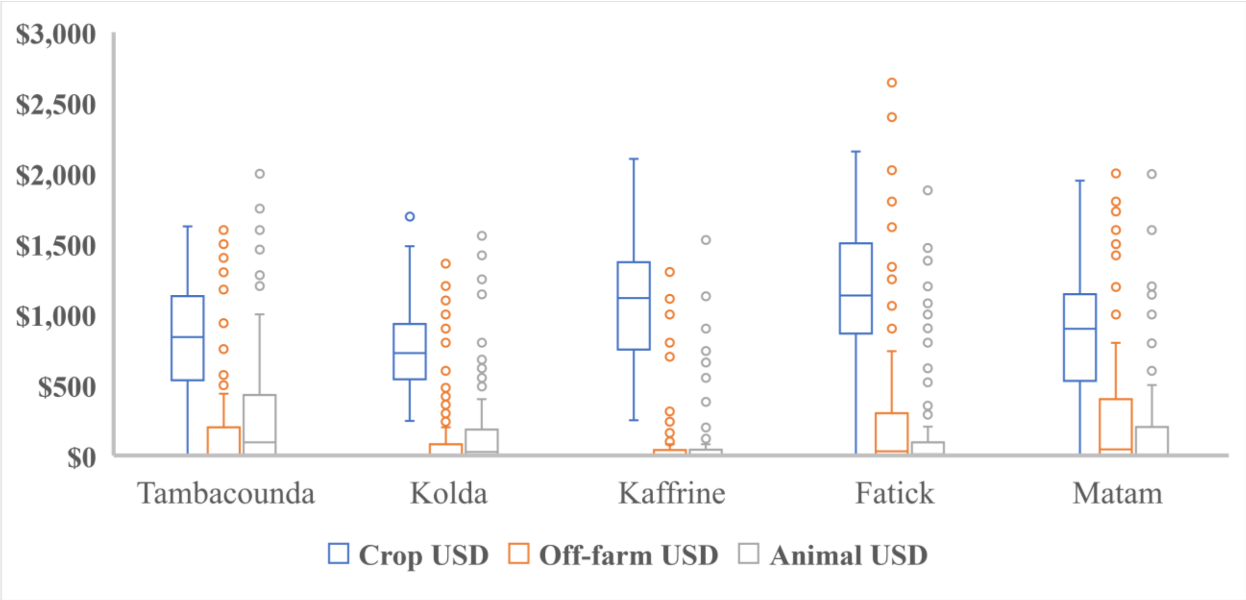


Figure A.9 (Senegal) Boxplot of *Zakat* and *Sadaqah* information

Figure A.10 (Ghana) Boxplot of Gender-headed Household Income

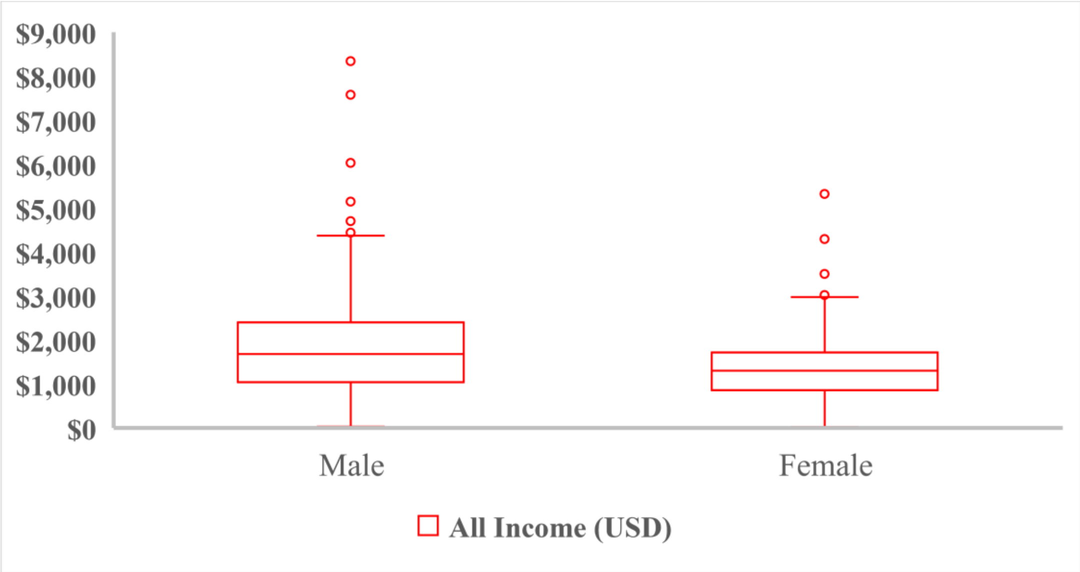


Figure A.11 (Liberia) Boxplot of Gender-headed Household Income

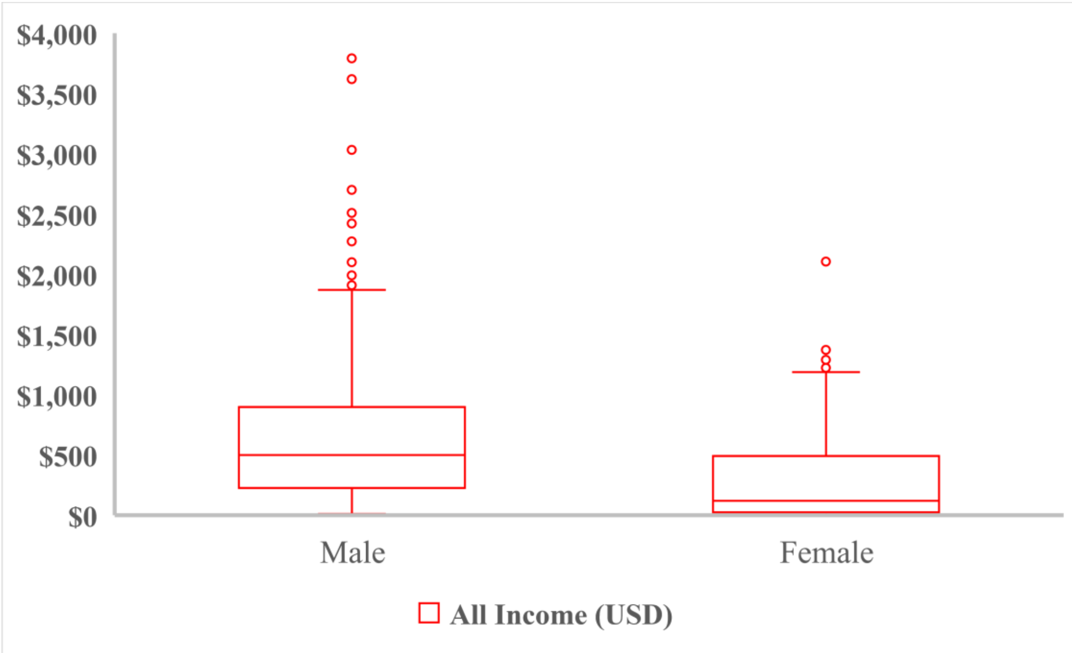


Figure A.12 (Senegal) Boxplot of Gender-headed Household Income

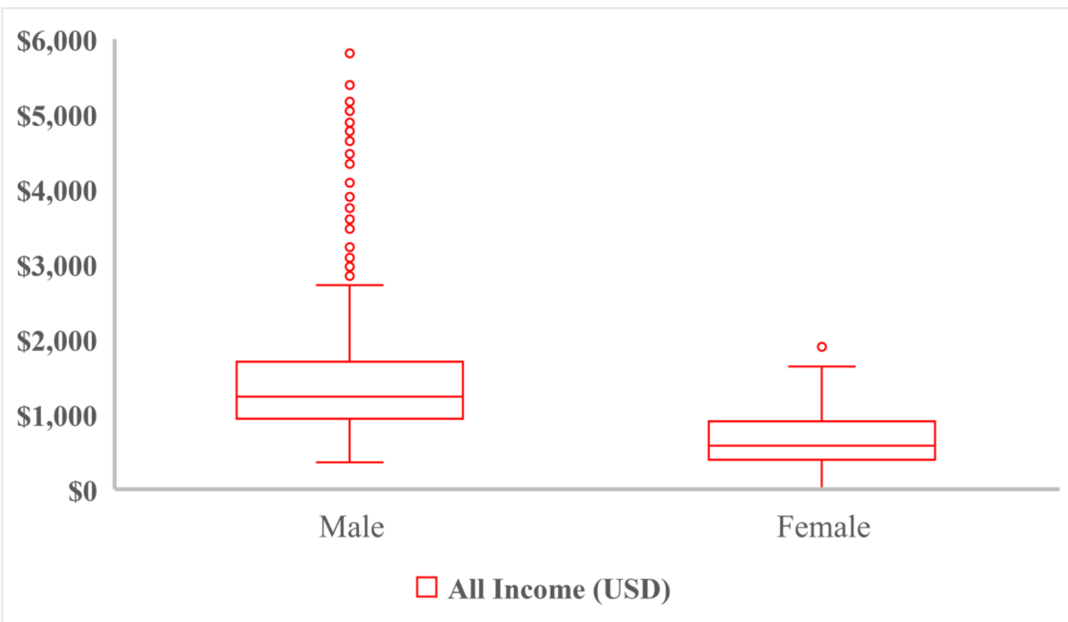


Figure A.13 (Ghana) Boxplot of Credited Amount by District

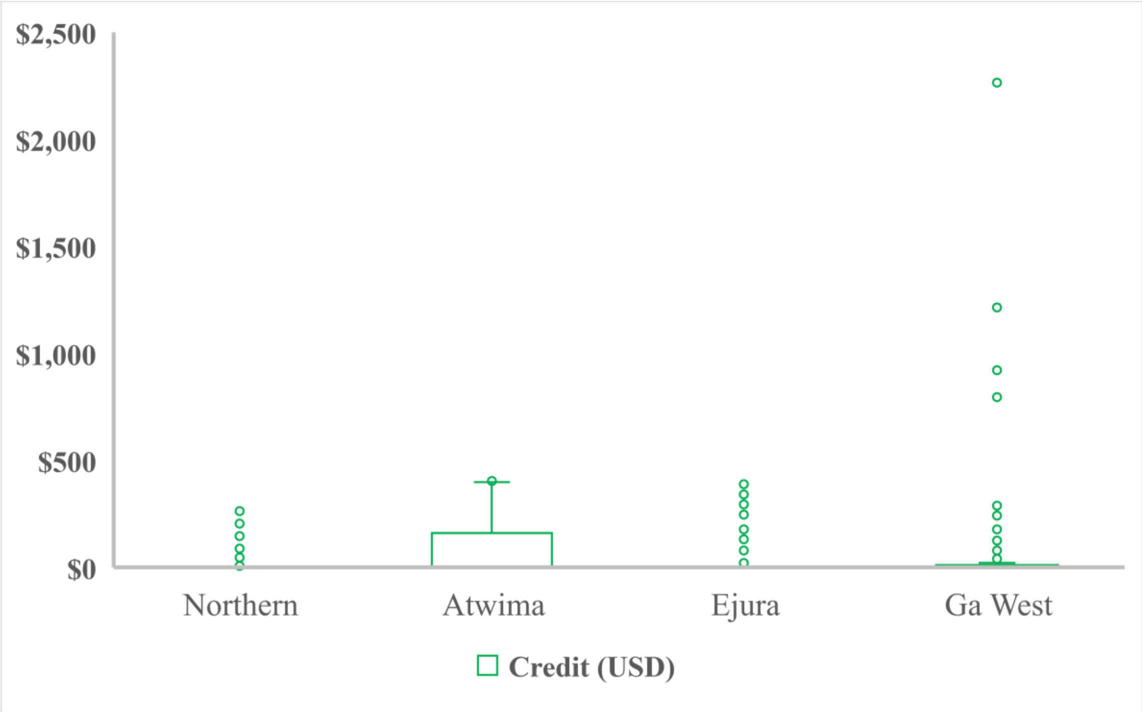


Figure A.14 (Liberia) Boxplot of Credited Amount by County

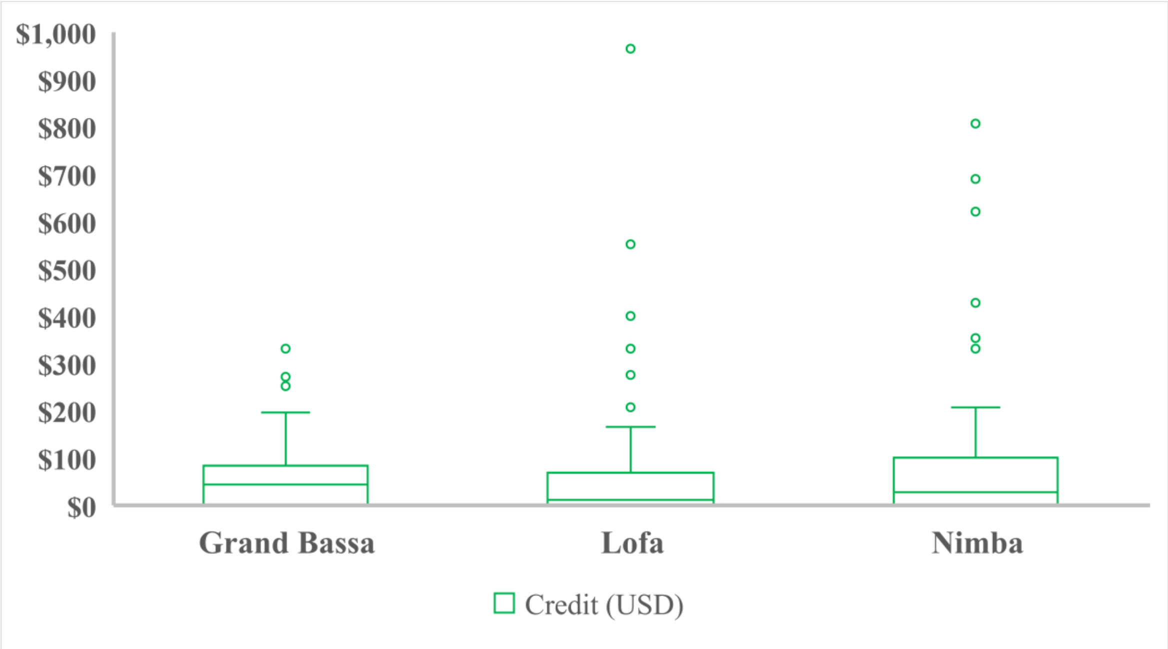


Figure A.15 (Senegal) Boxplot of Credited Amount by Region

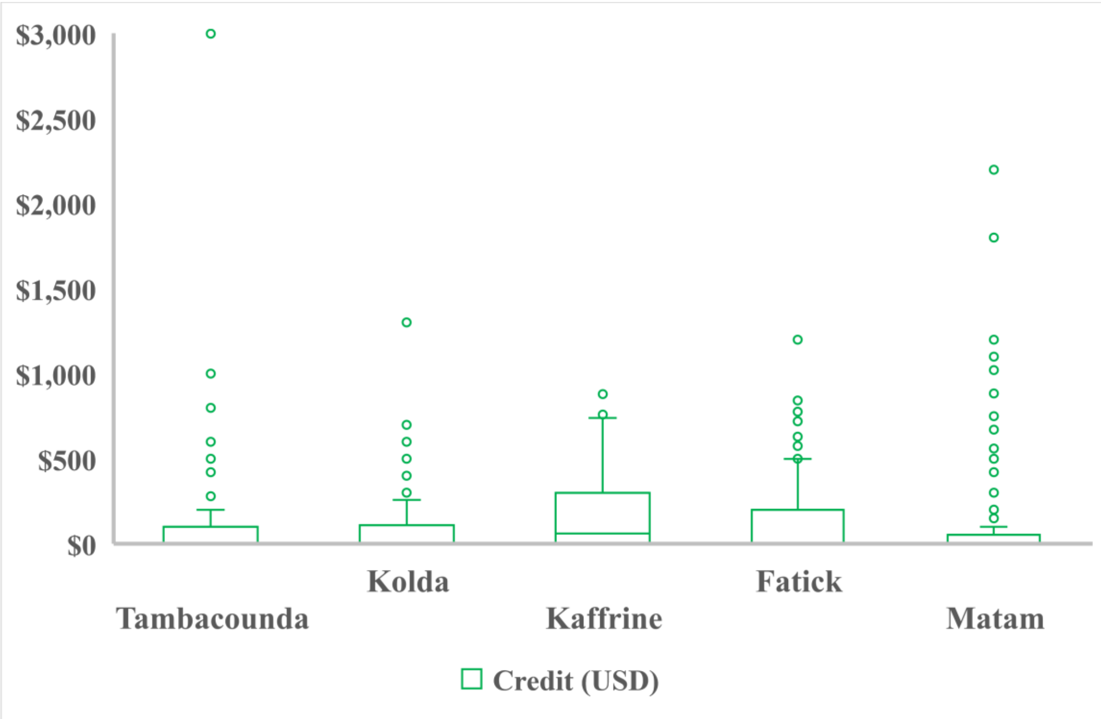


Figure A.16 (Ghana) Boxplot of Fertilizer and Herbicide/Insecticide Spent on Land by District

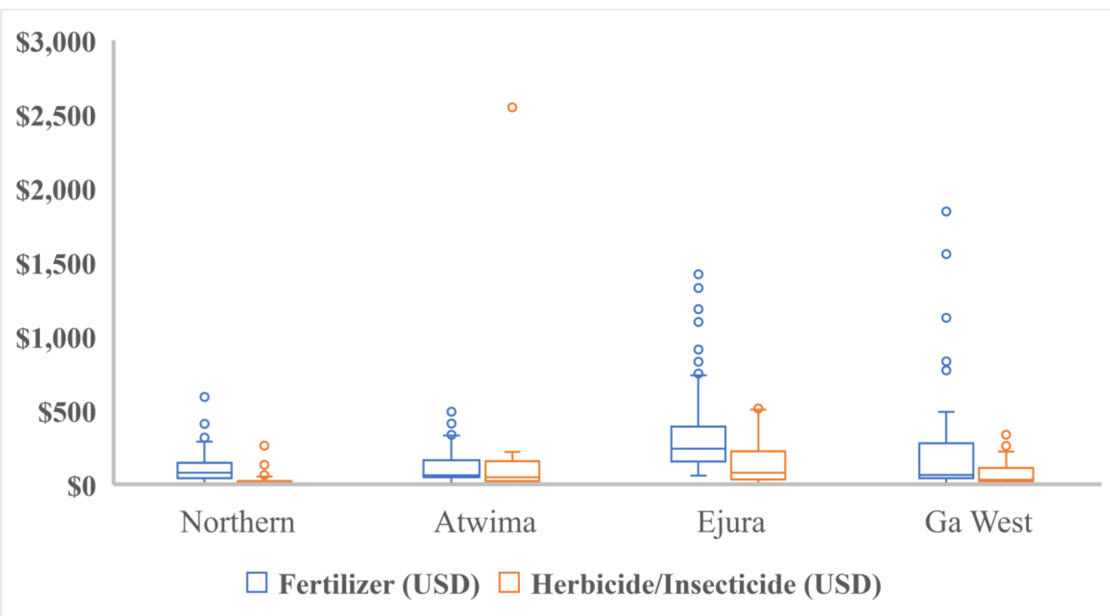


Figure A.17 (Ghana) Boxplot of Money Spent on Food Items by District

Figure A.18 (Ghana) Boxplot of the Number of Dependents, Family Labor and Outside Labor

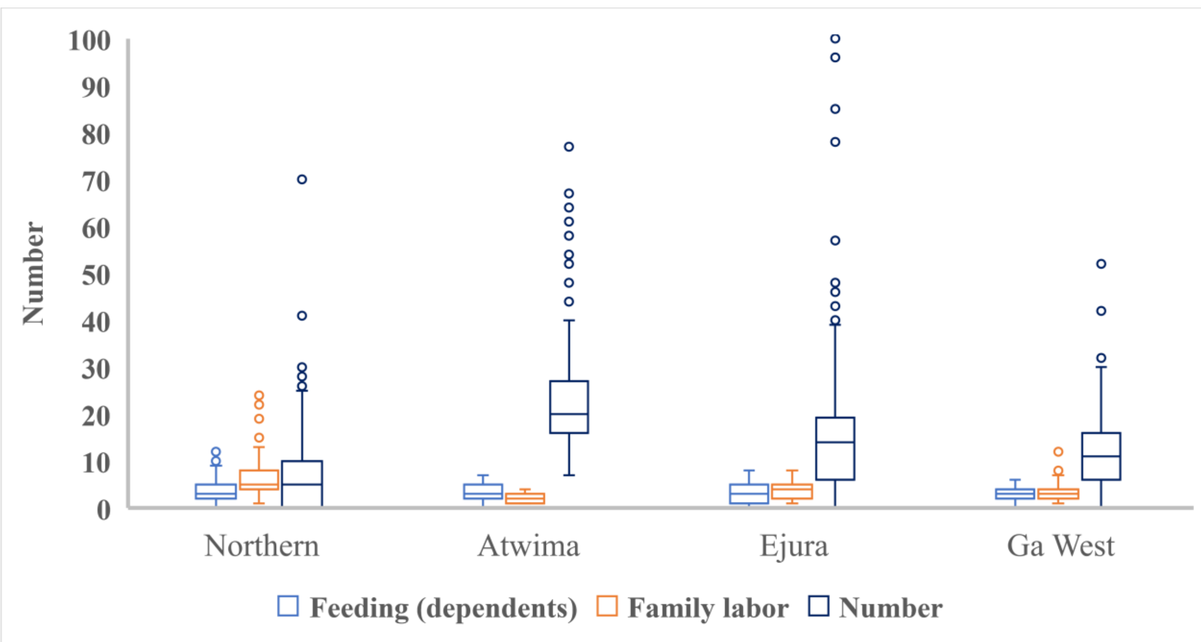


Figure A.19 (Liberia) Boxplot of the Number of Dependents, Family Labor and Kuu labor

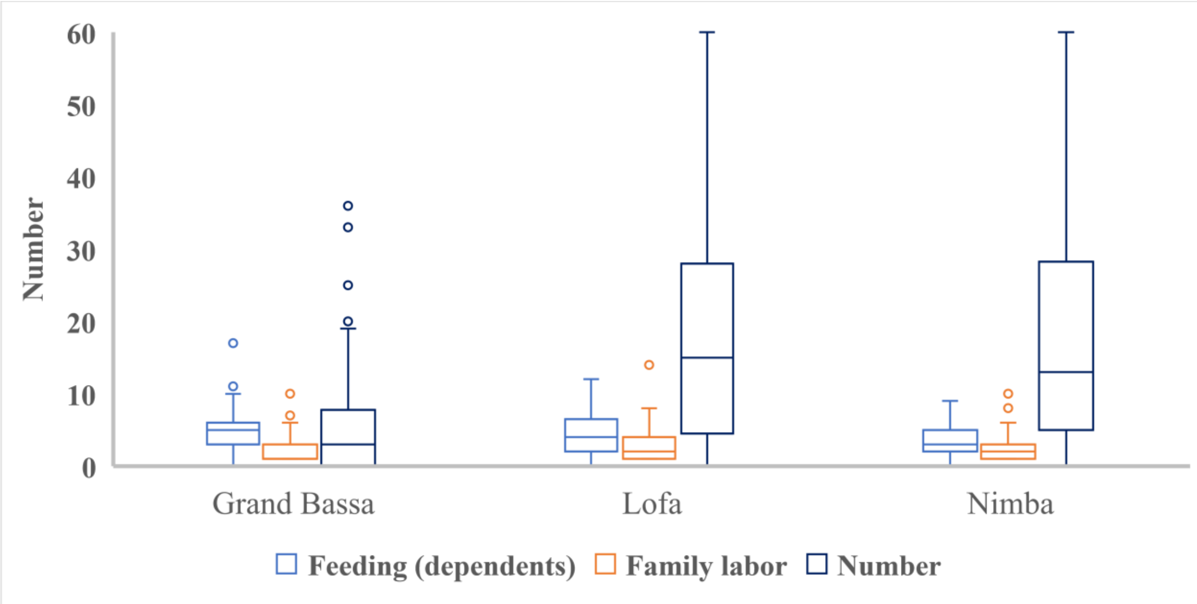
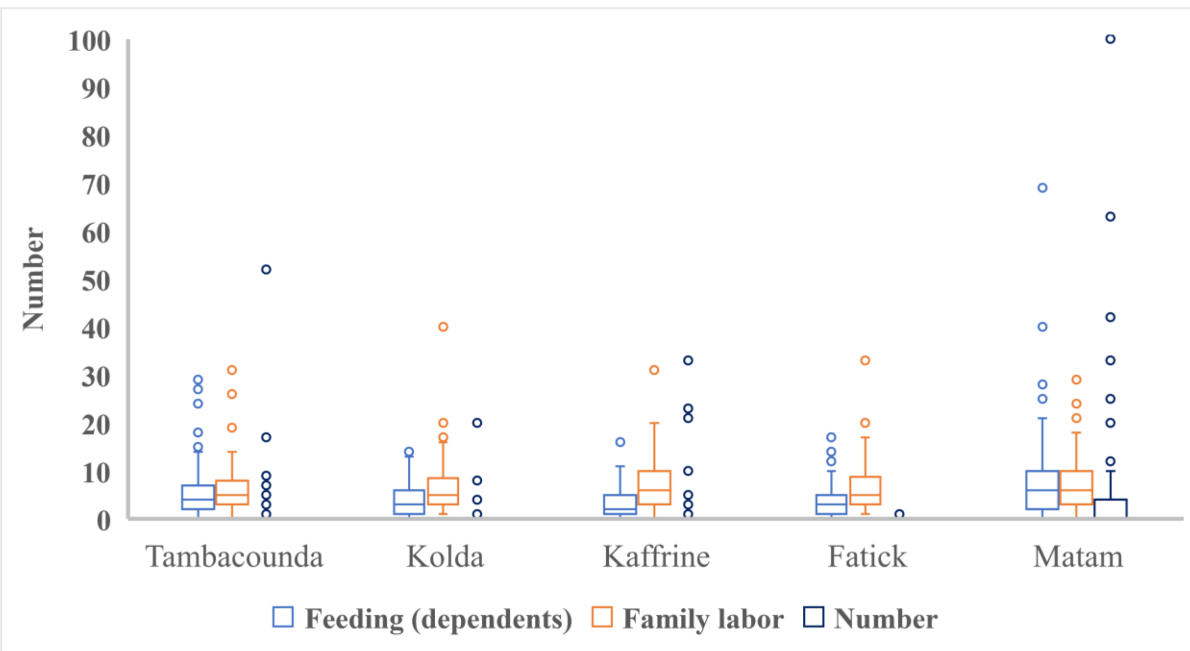
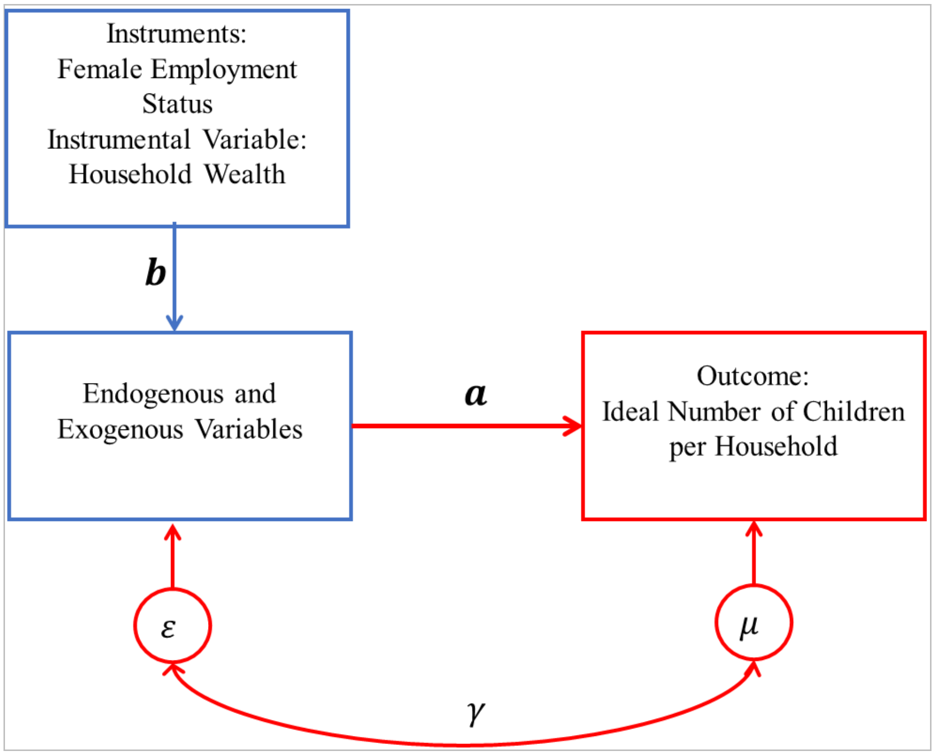


Figure A.20 (Senegal) Boxplot of the Number of Dependents, Family Labor and Outside Labor



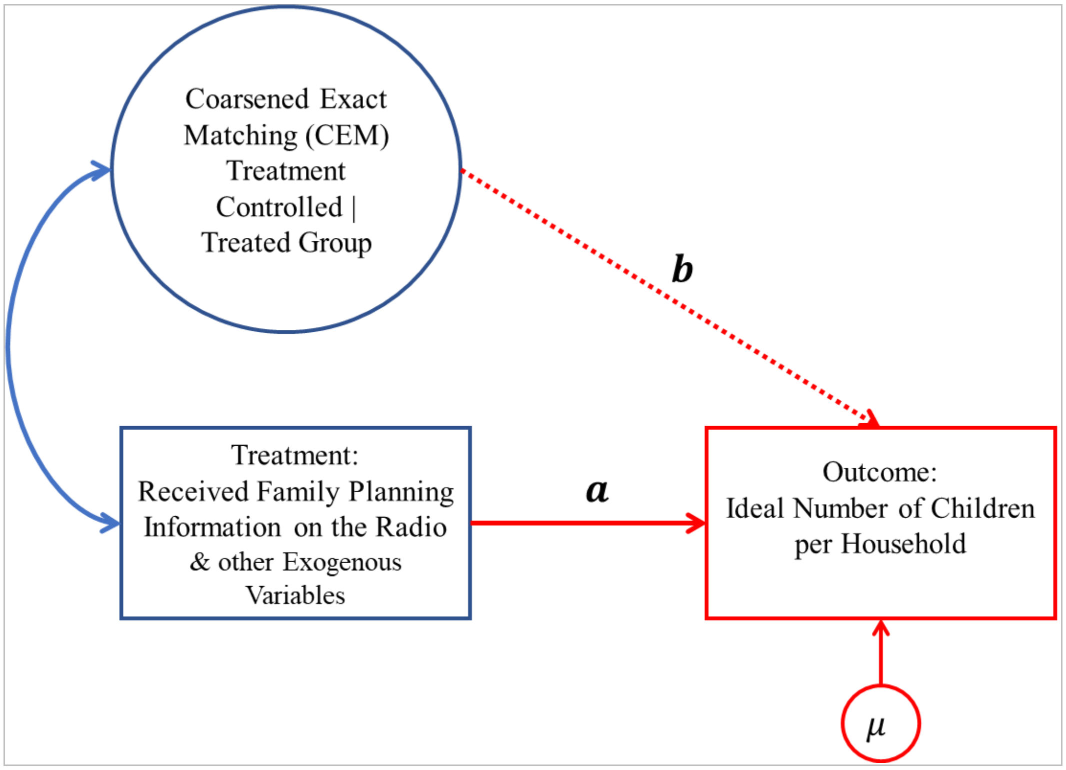
Chapter III

Figure A.21 IV Estimation Diagram



Direction '*a*' indicates the effect of the endogenous and exogenous variables on the outcome. Here residual correlation (γ) between our endogenous variable (ε) and the outcome (μ) interrupted the estimate. To measure factual causation, we must identify instruments that influence our endogenous variable in the first stage. Our endogenous variable with exogenous variables (including our treatment factor) can regress with the outcome variable in the second stage. Because our instruments and instrumental variable caused incorrect standard errors to the outcome variable, we performed two-stage least square regressions (path '*b*' to '*a*').

Figure A.22 CEM-weighted Regression Diagram



Direction '*a*' shows only our treatment and other exogenous variables change the outcome as we could control the path '*b*' through matching covariates (observed characteristics) between controlled and treated groups. The residual μ has no statistical relationship with treatment and exogenous variables.

Figure A.23 Stata IV Estimation Results (with Senegal 2016)

```
Instrumental variables (2SLS) regression          Number of obs   =      9,863
                                                  Wald chi2(5)    =     967.15
                                                  Prob > chi2     =     0.0000
                                                  R-squared       =     0.1026
                                                  Root MSE        =     2.1256

------------------------------------------------------------------------------
wantnumchild |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     wilevel |  -.7571476   .0616561   -12.28   0.000    -.8779913   -.6363039
  currentuse |  -.1500387   .0509064    -2.95   0.003    -.2498134    -.050264
    fpdesire |  -.4653148    .045496   -10.23   0.000    -.5544854   -.3761442
     treated |  -.1887111   .0527205    -3.58   0.000    -.2920413   -.0853809
 childdeaths |   .3311681   .0268811    12.32   0.000     .2784822     .383854
       _cons |   7.555568   .1708426    44.23   0.000     7.220723    7.890414
------------------------------------------------------------------------------
Instrumented:  wilevel
Instruments:   currentuse fpdesire treated childdeaths 2.resptypeearn
               respworked earnmls
```

Figure A.24 Stata IV Estimation Results (with Senegal 2018)

```
Instrumental variables (2SLS) regression          Number of obs   =     10,110
                                                  Wald chi2(5)    =     952.26
                                                  Prob > chi2     =     0.0000
                                                  R-squared       =     0.1069
                                                  Root MSE        =     2.1356

------------------------------------------------------------------------------
wantnumchild |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     wilevel |  -.7432036   .0610269   -12.18   0.000    -.8628141    -.623593
  currentuse |  -.1244467    .051039    -2.44   0.015    -.2244812   -.0244122
    fpdesire |  -.4966502   .0452824   -10.97   0.000     -.585402   -.4078984
     treated |  -.1418284   .0526291    -2.69   0.007    -.2449795   -.0386774
 childdeaths |   .3366283   .0268261    12.55   0.000     .2840501    .3892065
       _cons |   7.562295   .1694986    44.62   0.000     7.230084    7.894507
------------------------------------------------------------------------------
Instrumented:  wilevel
Instruments:   currentuse fpdesire treated childdeaths 2.resptypeearn
               respworked earnmls
```

Figure A.25 CEM-weighted Regression Results (with Senegal 2016)

Source	SS	df	MS			
				Number of obs	=	7,593
				F(4, 7588)	=	115.53
Model	2169.08856	4	542.272141	Prob > F	=	0.0000
Residual	35615.4696	7,588	4.69365704	R-squared	=	0.0574
				Adj R-squared	=	0.0569
Total	37784.5581	7,592	4.97689122	Root MSE	=	2.1665

wantnumchi~1	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
trt	-.2504516	.0497867	-5.03	0.000	-.3480474	-.1528559
currentuse1	-.3236181	.0565069	-5.73	0.000	-.4343873	-.2128489
childdeaths1	.5356961	.0286598	18.69	0.000	.4795149	.5918773
fpdesire1	-.5098478	.054322	-9.39	0.000	-.6163339	-.4033617
_cons	5.570439	.0423921	131.40	0.000	5.487339	5.65354

Figure A.26 CEM-weighted Regression Results (with Senegal 2018)

Source	SS	df	MS			
				Number of obs	=	7,601
				F(4, 7596)	=	121.50
Model	2364.14385	4	591.035962	Prob > F	=	0.0000
Residual	36949.9496	7,596	4.86439568	R-squared	=	0.0601
				Adj R-squared	=	0.0596
Total	39314.0934	7,600	5.17290703	Root MSE	=	2.2055

wantnumchi~1	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
trt	-.2295781	.050632	-4.53	0.000	-.3288308	-.1303254
currentuse1	-.2860933	.0567816	-5.04	0.000	-.397401	-.1747856
childdeaths1	.5690457	.029805	19.09	0.000	.5106197	.6274718
fpdesire1	-.6076589	.0555258	-10.94	0.000	-.7165048	-.4988131
_cons	5.66231	.0432569	130.90	0.000	5.577514	5.747105