IS AFRICAN AGRICULTURE EXHIBITING BOSERUPIAN INTENSIFICATION? EVIDENCE FROM RURAL GHANA AND NIGERIA

By

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ABSTRACT

IS AFRICAN AGRICULTURE EXHIBITING BOSERUPIAN INTENSIFICATION?
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The recent increase in the use of capital-using and labor-saving inputs in various parts of Africa has prompted researchers to investigate whether farming systems are innovating consistently with the Boserupian theory of intensification. According to the Boserupian theory, trends in factor price ratios will encourage farmers to substitute more expensive factors with less expensive factors. However, farmer responses to changing factor price trends may be blunted for many reasons, some of which could be addressed through public sector action. Using multi-year nationally representative surveys from Ghana and Nigeria, this study therefore broadly investigates the Boserupian hypothesis by analyzing how agricultural households in rural Ghana and Nigeria intensify input use in response to variations in relative input prices. Furthermore, this paper examines whether effects differ by geographic location within a particular nation. The findings from rural Ghana and Nigeria suggest that farmers intensify inputs partly but not entirely consistent with the Boserupian theory. These results indicate that household input use constraints may be systematically different, highlighting the need for regionally appropriate policies or programs that enable households to react more rapidly and entirely to changes in factor price ratios. This study could also provide policymakers, crop scientists, and engineers with insights into the expected trajectory of technical change in the farming systems and guide them in developing appropriate farm technologies and policies.

This thesis is dedicated to all graduate students facing some form of mental health problems. Don’t give up. Keep pushing, there is light at the end of the tunnel.

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1.0 INTRODUCTION

Technical change is an essential element in the growth of agricultural production and productivity from the very beginning of the developmental process of a country (Hayami and Ruttan 1971). The design, success, and adoption of an agricultural development strategy in each country consist of a particular route of productivity and technological change in response to the set of factor prices, which reflect the economic nature of resources in that country. Therefore, technological advances that save factors characterized by inelastic or slower supply changes become more productive for agricultural producers. To this end, farmers are compelled to look for technological alternatives that save the increasingly scarce factors of production due to relative input price changes (Hayami and Ruttan 1971). Hence, the land cost relative to labor and capital/cash inputs is likely to become increasingly important in influencing the technologies and integrated soil fertility management (ISFM) practices that will be attractive to farmers (Jayne et al. 2019).

Recent evidence indicates that an increasing proportion of African farmers have been using capital inputs such as herbicides, pesticides, fertilizers, and mechanization over the past two decades, many of which are labor-saving (for example, see Figures 1 and 2). The fertilizer usage rate in Sub-Saharan Africa increased from 9 to 16 kg/ha between 2000 and 2016, according to the World Development Indicators (2021). Again, in areas where the land frontiers have been reached, the growth in the recent fertilizer use represents increased commercial demand and incentives to optimize the net value of production per hectare of land (Sheahan, Black, and Jayne 2013). In Ghana, for instance, more than 60% of farmers used herbicides, according to the 2015 nationally representative rural household survey (Grabowski and Jayne 2016). In addition, herbicides were used on 73 percent of maize plots (Ragasa et al. 2013), 61 percent of yam farmers, and 44 percent of all chemicals applied to vegetable fields (Ntow et al. 2006).

Furthermore, in sparsely populated areas where labor is scarce, and medium-scale farms have invested, such as central and northern Ghana, the percentage of farmers using mechanization for land preparation has risen remarkably quickly, encouraging the growth of tractor rental markets (GSS 2016). Although there is little data on past rates of fertilizer use in Ghana, the level has been low but increasing. During the 1970s and early 1980s, there was an increase in fertilizer consumption but subsequently decreased between the late 1980s and 1990s. Since then, there has been a general increase in fertilizer use from the late 1990s, and as of 2002, consumption again was at 1980 levels (Banful 2009).

Similarly, in Nigeria, inorganic fertilizer is used by many smallholder farmers, and in many states, inorganic fertilizer is applied to over 70% of plots. Fertilizer use rates differ significantly across all plots (including zeros) and are often greater than 100kg per hectare (Liverpool-Tasie et al. 2017). Estimates from Nigeria's LSMS data from 2011 to 2018 indicate that more than 60% of rural households used fertilizer on their plots during the major planting season. Although there is evidence of an increase in capital inputs in Nigeria, the increasing labor supply due to the rapidly growing population coupled with continued low wages for hired agricultural work may induce farmers towards labor-using technologies. Hence, rural farmers would be more likely to shy away from capital-using technologies such as herbicides and mechanization due to the relatively low labor cost in rural areas. For example, Mutambara (2013) found a negative association between the size of the household and the use of herbicides by Nigerian farmers. This could be explained as the larger the household, the more family labor is available for small-scale farmers' agricultural operations. The less likely farmers are to use labor-saving techniques such as herbicides. Again, most rice farmers in Ogun State, Nigeria, do not know how to use herbicides, according to Akinbile (2007), which may indicate that they use other methods to weed their farms. Contrary to some studies, evidence suggests that Nigerian farmers are more likely to display capital-saving and labor-using farm production practices due to the relatively lower labor cost (Oluwatoyese and Razak 2016).

The slightly opposite input-use intensity trends in Ghanaian and Nigerian agricultural systems suggest highly heterogenous localized factor scarcities and price trends. As depicted in Table 1, there has been a significant increase in fertilizer, pesticide, and herbicide use per cropland area in Ghana between the years 1990 to 2019. Meanwhile, there has not been a substantial increase in Nigeria's fertilizer use per cropland area. Despite the numerous strategies by Nigerian governments to stimulate fertilizer use, including subsidies, extension, and increased farmers' access to credit, these programs did not significantly raise fertilizer demand (Nagy and Edun 2002). It has not been easy to estimate pesticide and herbicide use in Nigeria. However, by 1998, 125,000-130,000 metric tons of pesticides were projected to be applied annually in Nigeria (Ikemefuna 1998). Suppose African farmers' input use conforms to the Boserup theory of intensification. In that case, trends in relative factor prices may provide policymakers with insights into the trajectory of technical change in farming systems, anticipating, and more effectively supporting farmers through appropriate land, labor, and capital input supply policies.

According to the Boserupian Intensification, smallholder farmers will intensify based on changes in relative land and labor scarcities (Boserup and Chambers 2014). Boserup asserts that as population density increases, relative input prices will alter such that the relative scarcer factor, land, becomes more expensive relative to labor and capital, and that farmers will respond by intensifying their use of land by increasing the amount of fertilizer and labor per unit of cultivated land. This study, therefore, examines a more generalized form of the Boserupian hypothesis by assessing how agricultural households in rural Ghana and Nigeria intensify input use in response to changes in relative input prices. Specifically, this paper examines how households' use and intensity of fertilizer, herbicide, hired labor, and land rentals respond to changes in land, labor, fertilizer, and herbicide prices. In addition, this study investigates whether these relative price responses differ according to geographical location- that is, between the north and south- within a specific country[1].

Historically, northern parts of most sub-Saharan African countries lack the economic dynamism and infrastructure prevalent in the south. Households in the south have relatively better market access conditions than their counterparts in the north. In Ghana, market access varies considerably between the south and the north, with districts in the south having better connections to markets (Lall, Sandefur, and Wang 2009). Similarly, poverty in northern Nigeria is high (Amare et al. 2018) and transcends to poor market access conditions for rural households than those in the south. The choice of these inputs is determined by sufficient observations and variations in the data across space and time in all regions/zones. This gives us enough confidence to construct their respective prices across space and time[2]. In this analysis, I considered households primarily engaged in maize, cocoa, and cassava in rural Ghana. Similarly, in rural Nigeria, I considered households primarily engaged in maize, sorghum, and cassava. These staples are widely consumed in both countries and have become a mainstay for rural households. Hence their food and source of income greatly depend on the production's success.

[1] In Ghana, Upper West, Upper East, and Northern Regions make up North households, while the rest of the regions make up the south. For Nigeria, households in the northeast, west, and north zones make up the north, and households in the southeast, west, and south make up the south.
[2] I could not include other capital-using inputs like tractor rentals, pesticide use, and mechanization in our model due to insufficient information and missing data.

This study makes two significant contributions to the extant literature on the consistency of the Boserupian intensification in sub-Saharan Africa (SSA) agricultural production. First, this paper broadens the Boserupian intensification literature by examining how households' systematic differences in market access conditions alter input demand in response to relative input prices using a nationally representative panel survey. Only a few existing literatures tests the heterogeneity in households' behavior towards changes in relative input price. For instance, (Kopper and Jayne 2019) assesses whether households' response to changes in relative factor pricing varies depending on market access and agroecological potential using a panel of 1208 smallholders in Kenya. However, this paper does this in the context of households' areas under cultivation, fertilizer use, and intensity. My paper broadens this further by including additional inputs like herbicide and hired labor. These other inputs, in most cases, represent the conventional inputs used in agricultural production in rural Africa. Second, this study provides inter-country and intra-country analyses of differences in household responses towards the highly heterogenous localized factor scarcities on demand for inputs.

I organize the rest of the paper as follows. In section 2, I offer a theoretical/conceptual framework that models households' input demand as a function of input prices. Section 3 presents a detailed discussion of the data. The empirical model is presented in section 4, discussing the estimation and identification strategies. In section 5, descriptive statistics and preliminary and empirical results are presented and discussed. Section 6 concludes with policy implications.

2.0 CONCEPTUAL FRAMEWORK

In this section, I present a simple conceptual framework to model the rural households' demand for conventional inputs - commercial fertilizer, land rental, herbicides, and hired labor - as a function of input prices. I follow Singh, Squire, and Strauss (1986) Agricultural Household Model (hereafter AHM), in which households are simultaneously involved in production and consumption. However, I tweaked this model to conceptualize how changes in the relative input prices affect the rural households' demand for these conventional inputs.

I first assume separability between consumption and production decisions under the standard AHM. This implies that production and resource allocations can be decided independently of consumption decisions when separability occurs. However, when a market failure occurs, separability breaks down, and production and consumption decisions must be taken jointly (Simtowe and Zeller 2006). Consequently, under separable assumptions, the household, to some extent, trades on a complete set of perfectly competitive markets. This includes, among other things, the household being a price taker of all goods produced and consumed, including labor. Admittedly, I do not dispute the fact that in the rural setting of our model, all the assumptions of separability could be met. However, for simplicity and practicality, I proceed with separability assumptions.

Following Singh et al. (1986), consider a static profit maximization problem of rural households producing agricultural outputs[3]. It is worth noting that this static approach to profit maximization does not model the dynamics of technology adoption over time that involves the endogenous development of new technologies. To this end, this study focuses primarily on how rural households are intensifying inputs in response to changes in relative factor prices.

[3] As noted, I used the production of maize, cocoa, and cassava in rural Ghanaian and maize, sorghum, and cassava in rural Nigeria.

Let the production function of a rural household be given by;

$$h(q, x, z) = 0 \quad (1)$$

where q is a vector of output quantities, x is the vector of input quantities, and z is a vector of quasi-fixed factors and household characteristics affecting production like weather, household size, distance to the nearest tarmac road, etc. Variable inputs may include hired labor, fertilizer, herbicides, and hectares of rented land, which could be bought in desired amounts. Let w and p be vectors of input and output prices, respectively. The households' farm profits can be written as follows;

$$p'q - w'x \quad (2)$$

The household is assumed to choose a combination of variable inputs and outputs that maximize profit subject to technology constraints:

$$\max_{q,x} p'q - w'x \quad , \text{ s.t } h(q, x, z) = 0 \quad (3)$$

The solution to this maximization problem is a set of reduced form input and output supply functions that can be written as;

$$x = x(p, w, z) \quad \text{and } q = q(p, w, z) \quad (4)$$

Hence, with the reduced form of input demand as a function of input and output prices, it is possible to estimate the effect of relative input prices on households' demand for inputs in rural Ghana and Nigeria.

3.0 DATA

This paper is based on four waves of Nigeria's Living Standards Measurement Study-Integrated Survey on Agriculture (LSMS-ISA) and two waves of the Ghana Socioeconomic Panel Survey. The LSMS-ISA for Nigeria is a panel dataset administered by the World Bank, the National Bureau of Statistics (NBS), and the Federal Government of Nigeria (FGN). The sample frame includes all thirty-six (36) states of the federation and Federal Capital Territory (FCT), Abuja. Both urban and rural areas were covered, and 5000 households were interviewed in the first wave. This data is representative of the national, rural, and urban levels and the six geopolitical zones of Nigeria.

The LSMS-ISA includes geo-referenced plot locations and plot-level information on input use, cultivation, and production. Enumerators collected information over two visits per household per each survey period covering the first wave (2010/2011), the second wave (2012/2013), the third wave (2015/2016), and the fourth wave (2018/2019). The first visit, which covers information on post-planting activities, begins in August and ends in October of the starting year of each survey. The second visit, which covers information on post-harvest activities, starts in February and ends in April, the ending year of each survey. For this analysis, variables of interest were constructed based on information gathered during the major planting season, where there are sufficient observations over time and robust results across model specifications. Thus, I extract all plots of maize, sorghum, and cassava grown during the main agricultural season. These crops are grown on more than 60% of plots in each survey period. Table 3 describes selected variables used in estimation in rural Nigeria.

The Ghana Socioeconomic Panel Survey was conducted in the years 2009/10 (Wave 1) and 2014/15 (Wave 2) by the Economic Growth Center (EGC) at Yale University and the Institute of Statistical, Social, and Economic Research (ISSER) at the University of Ghana-Legon. This nationally representative survey was designed to monitor Ghana's living standards and economic conditions. Enumeration areas (EA) were randomly selected throughout the ten (10) regions in Ghana, and 15 households were selected from each EA. Overall, 5009 households were interviewed across the ten regions about various socio-economic and demographic topics such as employment, education, health, labor market activities, and agricultural production. The data collection typically starts in November of the starting year and ends in April of the ending year. Variables of interest were constructed from information on the major planting season where there are enough observations over time. Likewise, cultivated plots with maize, sorghum, and cocoa were considered and analyzed during the main agricultural season. These crops account for over 65% of all crops grown on plots in each survey period. Table 2 describes selected variables used in estimation in rural Ghana.

To address the challenge associated with extreme outliers, I follow similar methods adopted by Liverpool-Tasie et al. (2017) in dealing with extreme outliers in the data. The dependent and independent variables were winsorized at 99% or 95% in cases where 99% still gave us seemingly large values. This is achieved by replacing the outlier values beyond the 99^{th} percentile with the value at the 99^{th} percentile rather than forcing the values to a no observation.

3.1 Computation of Input Prices

3.1.1 Price of Fertilizer Per Kilogram

Prices of fertilizer were reported as the total amount paid for a quantity of fertilizer purchased expressed in the national currency (Naira in Nigeria and Cedis in Ghana). I used that information to calculate the price of fertilizer per kilogram. For Ghana and Nigeria, the questions about the purchased fertilizer (type, source, and amount used) and the quantity of purchased fertilizer were at the plot level. I computed the fertilizer price by first dividing the total price paid for fertilizer by the total quantity of fertilizer purchased on all plots by the household in the major planting season. After that, I averaged the price of fertilizer per kilogram into household-level prices. The local-level (that is, district level for Ghana and Local Government Area level for Nigeria) median household price is used when there are no observations or missing values for fertilizer transactions for a particular household. In my econometric regressions, all households face their corresponding calculated input prices and local level median household prices for households with no observation in fertilizer transactions. This is because it is plausible to assume that, in rural SSA, most households face comparable prices of inputs at the local level.

For fertilizer prices in Ghana, the data did not specify the type of inorganic fertilizer. Hence, the money amount and quantity comprise all the fertilizer the household might have purchased or used during the major planting season. This left us with little chance to compute the price for a particular type of fertilizer. Therefore, I generalized the price of fertilizer as the price of inorganic fertilizer the household purchased without referring to any kind. Unlike the data for Nigeria, the LSMS-ISA reported different types of fertilizer, e.g., NPK and urea. Even though this data did not specify the N, P, or K content, this study focused on NPK price since it is the product with the most observations across space and time.

3.1.2 Price of Herbicide Per Liter

For the herbicide price per liter, I followed a similar procedure in calculating the household level price of fertilizer. The LSMS-ISA and GSS reported the price of herbicide as the total amount paid for a quantity of herbicide expressed in the national currency and the total amount purchased. I used that information to calculate the price of herbicide per liter. The questions about the purchased herbicides and the quantity of purchased herbicide were at the plot level in both data sets. I then first computed the price of herbicide per liter at the household level by dividing the total money amount of herbicide purchased by the total quantity purchased on all plots. Similarly, I used local-level household median herbicide prices for households without observations.

3.1.3 Agricultural Wage Per Day

The agricultural wage is obtained by dividing the amount each household spent on all agricultural production on the farm by the quantity of labor per day, excluding family labor. This includes men and women who were hired to perform some form of agricultural activities on people's farms. I used the median household agricultural wage paid at the local level if a household had no observation.

3.1.3 Price of Rented Farmland

I computed the price of rented farmland by dividing the money paid by the size of the plot leased in hectares. Again, both data sets reported the price paid and the size of the hired plot at the plot level. I, therefore, followed similar methods employed above to estimate household-level prices. If there is no observation, I used the local level's median price of hired land per hectare.

3.1.4 Price of Outputs (Sorghum, Maize, Cassava, and Cocoa)

I estimated realized output prices by dividing the total sales received by the total quantity sold at the household level during the major harvest season. Again, I computed the local-level median price of each output as the output price for households with no or missing harvest observations.

4.0 EMPIRICAL MODEL

4.1 Choice of Double Hurdle Model

One of the challenges associated with estimating relative input price effects through a model of input demand is that a large percentage of the rural households in SSA do not purchase some of the conventional inputs. Because a significant proportion of households report zero input use, it may appear feasible to adopt a Heckman selection strategy in this situation. However, since the conventional inputs studied in this study have been available in Ghana and Nigeria for decades, it is safe to assume that most rural households are aware of them. Hence, a corner solution model is more appropriate than a selection model for this problem (Wooldridge 2003). However, many choose not to purchase or use some of these inputs owing to market and agronomic conditions. As a result, the zeros in the data most likely represent rural households' optimal choices rather than missing values.

The conventional Tobit model, first proposed by Tobin (1958), has been used in the past to cope with data having too many zeros, resulting in a censored dependent variable. The model allows all observations to be included, including those censored at zero, without considering the sources of the zeros. Because the Tobit model ignores zero observations due to respondents' non-participation decisions, it imposes the assumption that all zeros arise from other factors such as the economic and demographic characteristics of the respondents (Wodjao 2020). However, the Tobit model is restrictive because it requires a decision to purchase an input, and the amount to be bought is determined by the same process.

The Double Hurdle Model (DHM) proposed by Cragg (1971) to address corner solution models is more flexible than the Tobit because it accounts for the possibility that factors affecting input market participation and factors influencing the quantity of input purchased may be different.

Also, Cragg (1971) changes the Tobit model to overcome the restrictive assumption inherent in it. Notably, he proposes the "double-hurdle" model to address the problem of too many zeros in survey data by treating the participation decision differently. The DHM fits our problem of estimating the effect of relative input price changes on demand for cheaper inputs because it allows for the fact that the price of one input, say the price of fertilizer, may affect rural households' decision to participate in the market. Still, once the decision to participate in the market has been made, the price of fertilizer may not affect the quantity purchased.

Furthermore, the DHM allows a factor to affect participation and the amount purchased/used differently. The first hurdle involves rural households' decision to participate in an input market, and if they do, the second hurdle considers the quantity of input purchased or consumed. In general, the first hurdle refers to the participation or ownership decision, and the second to the level of intensity of use. The first hurdle's maximum likelihood estimator (MLE) can be obtained using a Probit model. Then the MLE for the second hurdle is estimated from a truncated normal regression.

4.2 Econometric Model Specification

I estimate the reduced form input demand function from our conceptual framework by implementing a DHM related to the decision or likelihood of rural households to demand inputs. The binary decision can be modeled as follows an index function using a probit model as follows:

$$Y_i^* = \boldsymbol{S}'_i \alpha + \varepsilon_i, \qquad \varepsilon_i \sim N(0,1) \tag{5}$$

Where $Y_i = 1$ if $Y^* > 0$ and $Y_i = 0$ if $Y^* \leq 0$

Y_i is a dichotomous variable that takes the value of 1 if the household purchases or uses farm inputs and 0 otherwise. S is a vector of explanatory variables, α denotes a vector of parameters, and ε is the error term.

The empirical model for rural household's decision to use farm inputs is specified for this study as follows:

$$\text{arcsinh}\ (Y)_{ijrt} = \alpha + arcsinh(\boldsymbol{P}'_{ijrt}\boldsymbol{\varphi}) + \ \gamma\text{arcsinh}\ (D)_{jrt} + \boldsymbol{H}_{ijrt}\boldsymbol{\delta} + \boldsymbol{\mu}_t + \boldsymbol{\xi}_r + (\boldsymbol{\mu}_t \times \boldsymbol{\xi}_r)\boldsymbol{\beta} + \boldsymbol{\varepsilon}_{ijrt} \qquad (6)$$

Where i indexes households, j indexes districts in the context of Ghana and Local Government Area (LGA) in Nigeria, r indexes regions in Ghana and zones in Nigeria, and t indexes time. Y measures the households' decision to use a particular input or not, $\boldsymbol{P}$ is a vector of input and output prices consisting of inorganic fertilizer, herbicide, rented land, hired labor, cocoa, sorghum, cassava, and maize. $\boldsymbol{H}$ is the vector of household and plot characteristics such as the age in years of the household head, whether or not the household head is a male/female, the size of the household (number of people living within the household at a time), household distance in kilometers to the nearest market, the slope of the plot, the monetary value of household durable asset and households' landholding size (see tables 2 and 3 for a complete list of variables used and their description). D is the population density at the district or LGA level. $\boldsymbol{\mu}$ is the year fixed effect, $\boldsymbol{\xi}$ is the geographic fixed effect (region in Ghana and zones in Nigeria)[4]. $(\boldsymbol{\mu}_t \times \boldsymbol{\xi}_r)$ is the interaction term between year and geographic fixed effects[5]. α $\boldsymbol{\varphi}, \beta$, γ are parameters to be estimated, and $\boldsymbol{\varepsilon}$ is the error term. It is worth noting that households did not know realized output prices before deciding to cultivate crops or purchase inputs. Hence by including output prices in the model, I introduce endogeneity into the model. However, omitting the realized output prices from the econometric model also poses severe misspecification problems. To this end, realized

[4] There were ten regions in Ghana and six zones in Nigeria as of when the data was collected.

[5] Due to my dataset's high number of households, I could not include an estimate a household fixed effect due to overparameterization and non-convergence of maximum likelihood functions.

output prices were included in the model as model misspecification may cause greater bias to the coefficient estimates endogeneity.

To interpret results in elasticities, I applied the inverse hyperbolic sine (or arcsinh) transformation instead of the usual natural logarithm transformation (or ln). Taking a variable's logarithm does not allow the retention of zero-valued observations because $\ln(0)$ is not defined. However, the arcsinh is most preferred and feasible because it is similar to logarithm and allows retaining zero-valued observations (Burbidge, Magee, and Robb 1988; MacKinnon and Magee 1990; Pence 2006)[6].

The second equation in the double hurdle relates to the amount or quantity of inputs used by the rural farmers conditional on the first hurdle being passed. The second hurdle equation can be estimated using a regression truncated at zero with the following formulations;

$$V_i^* = \boldsymbol{Q}_i'\zeta + \nu_i, \tag{7}$$

Where $V_i = 1$ if $Y^* > 0$ and $V_i = 0$ if $V^* \leq 0$

V_i represents the observed quantity of inputs used, which depends on the latent variable $Y^* > 0$, Q_i denotes a vector of explanatory variables, ζ represents a vector of parameters to be estimated, and ν_i is the random error term.

Empirically, the truncated regression model is specified for this study as follows:

$$\text{arcsinh}\,(V)_{ijrt} = \sigma + \text{arcsinh}\,(\boldsymbol{P}'_{ijrt}\boldsymbol{\omega}) + \gamma\text{arcsinh}\,(D)_{jrt} + \boldsymbol{H}_{ijrt}\boldsymbol{\varrho} + \boldsymbol{\mu}_t + \boldsymbol{\xi}_r + (\boldsymbol{\mu}_t \times \boldsymbol{\xi}_r)\boldsymbol{\lambda} + \boldsymbol{\eta}_{ijrt} \tag{8}$$

Where i, j, r, t maintains the exact definition in equation (6). V measures the number of inputs used or purchased by rural households during the major planting season. The rest of the

[6] See Appendix B on how elasticities are computed using the arcsinh transformation.

independent variables follow the exact definition in equation (6). σ , $\boldsymbol{\omega}$, ϱ, and λ are parameters to be estimated, and η denotes the random error term.

In the empirical specification of the model, input prices are assumed exogenous, and I added additional variables to control for any heterogeneities that may confound the estimation of the parameters of interest. After controlling for household demographics and plot characteristics, I added a population density variable (D) at the local level as an additional control variable since the behavior of households towards changing input prices depends on the population density according to the induced innovation hypothesis. Figure 2 in Jayne et. al (2019) tries to explain how population density affects input prices and how households respond to it. Willy, Muyanga and Jayne (2019) use farm-level analysis to present the importance of population density in adopting farm management practices among households in SSA. Again, I included a geographic fixed effect (a region in Ghana and zones in Nigeria) to control for any heterogeneity arising from the differences in regions and zones in Ghana and Nigeria, respectively. Lastly, an interaction term between year and region fixed effects ($\boldsymbol{\mu}_t \times \boldsymbol{\xi}_r$) was introduced in the regression to control for the biases arising due to the differences in regions and zones across time. For instance, year-by-region interaction will account for changes in regional policies that affect variables of interest (prices of inputs) and outcome variables (input demand).

The original Cragg (1971) model assumes that the errors between hurdle one and hurdle two (ε and η) are independent and normally distributed. The covariance between the two errors is zero, conditional on the explanatory variables. Several research, notably Garcia and Labeaga (1996) and Jones (1992) have relaxed the independent error term assumption, but the results were identical whether the assumption was relaxed or not. As a result, the independent error term assumption is maintained in this article.

5.0 RESULTS

5.1 Descriptive Statistics

Tables 4 and 5 show the descriptive statistics by survey wave of the main variables of interest in rural Ghana and Nigeria. In rural Ghana, the distribution of the outcome variables (fertilizer demand, herbicide demand, commercial labor demand, and farmland rental) indicates a large percentage of zero values of input demanded in each wave.

Table 4 suggests that the distributions of our outcome variables in rural Ghana are negatively skewed, hence the need to apply an appropriate estimator. In real terms, I also observe significant variations in overall input prices between 2009 and 2015. For instance, fertilizer prices varied by more than 400% between the 25th and 90th percentiles in the first survey year and 218% in the second survey year. Most of these intra-years spatial input price variations are likely because some households could have acquired fertilizers below market cost through input subsidy programs and due to differences in marketing and transportation costs. There are wide variations in household wealth within the sample. Asset wealth is over 70 times at the 90th percentile than the 25th percentile in both survey waves. The mean household landholdings are less than 5 hectares in both survey periods. This ranges from 1.01 hectares at the 25th percentile of households to 6.2 hectares at the 90th percentile in the first wave and from 0.8 hectares at the 25th to 6.06 hectares at the 90th percentile. This underscores the findings of other studies that suggest that most rural households in Ghana are smallholder farmers with landholdings less than 5 hectares (for example, see IFAD (2006); Chamberlin (2007); Nyanteng and Seini (2000)).

Similarly, in rural Nigeria, Table 5 shows that the distribution of the outcome variables is also negatively skewed. There was also an overall variation in input prices in all the survey periods. Fertilizer prices varied by over 40% between the 25th and 90th percentiles of fertilizer prices in the first survey year, over 25% in the second, over 70% in the third, and 20% in the last survey year in real terms. The median price of herbicide almost doubled in real terms between the first and the last survey period. The intra-year spatial variation is likely caused by marketing and transportation cost differences. Table 5 also shows an increasing trend in mean household size in Nigeria, which in the first, second, third, and fourth surveys is 6.2, 6.8, 7.9, and 8.5 persons, respectively. This trend also echoes the rising nature of the Nigerian population.

5.2 Preliminary Results

5.2.1 Trends in Relative Input Price Ratios in Rural Ghana

Figure 3 depicts rural Ghana's relative input price ratios between 2009 and 2015. Between these years, the median agricultural wage (Ghana cedis per day, GHS/day) rose faster than land rental rates (GHS/Ha) and fertilizer prices (GHS/Kg). Figure 3 shows that, in comparison, the agricultural wage-fertilizer price ratio increased slightly over 40% between 2009 and 2015. Similarly, the agricultural wage-land rental price ratio increased slightly above 20% between 2009 and 2015. A couple of reasons could explain the trend in input price ratios. First, Ghana has witnessed a rapid economic transformation and demographic change since 2000. This transformation includes rising off-farm wage rates, which has induced rural-to-urban migration, intra-rural migration, and the rapid shift of the labor force from farm to off-farm employment (Jayne et al. 2019). Furthermore, Christiaensen and Todo (2014) and Yeboah and Jayne (2018) share a similar view that expanding opportunities for cash-earning off-farm work is more likely to exert increasing pressure on rural wage rates in such locations. Following this trend in input prices, I test the explanatory power of the Boserupian theory of intensification by hypothesizing that a rising agricultural wage rate relative to other input prices is more likely to have a positive impact on the demand or use of labor-saving and capital using inputs such as inorganic fertilizer and herbicides among agricultural households in rural Ghana.

5.2.2 Trends in Relative Input Price Ratios in Rural Nigeria

Conditions in rural Nigeria are different. Figure 4 shows that the median agricultural wage (naira per day, N/day) plummeted against the price of inorganic fertilizer (N/kg) and the cost of land rental (N/day) between the years 2011 and 2019. Furthermore, Figure 4 shows that comparing these three inputs, the agricultural wage-fertilizer price ratio fell by 16% between 2011 and 2019. Similarly, the agricultural wage-land price ratio decreased by approximately 50% between 2011 and 2019. Land rental prices rose faster than both agricultural wages and fertilizer prices.

Nigeria has lacked the economic dynamism that Ghana has enjoyed over several decades, leading to slower growth in off-farm wages. For these reasons, agricultural labor in Nigeria has remained relatively abundant, further due to continued rising population growth. Amid the high population growth, shrinking off-farm opportunities lead more people back into the agriculture sector, further depressing agricultural wages relative to farming, compared to only 34% for Ghana (Yeboah and Jayne, 2018). This phenomenon results in an expansion of the total agricultural labor supply, and hence given demand lowers the existing agricultural wage per day relative to other inputs. It must be known that even though rural-urban migration is prevalent in some rural areas in Nigeria, its net effect is not much to cause significant changes in the agricultural wages even though it is likely to cause slight changes in price in those rural areas experiencing these out migrations. Not surprisingly, it is plausible that given Nigeria's rising population, agricultural land eventually becomes scarce and, as a consequent increase in land values. Similarly, following the trend in input prices, I test the explanatory power of the Boserupian theory of intensification by hypothesizing that the falling agricultural wage rate against the prices of other inputs is more likely to have a positive impact on the demand or use of commercial labor (land-saving, capital-saving, and labor-using) for agricultural production.

5.3 Econometric Results

Tables 6,7,8, and 9 present the two-part Double Hurdle Model (DHM)[7] for input demands by rural households in Ghana and Nigeria. Hurdle one represents the probit regression which captures the probability of households participating in the input market. At the same time, hurdle two means truncated normal regression, which measures the intensity of input use conditional on participation. The coefficient of variables of interest represents elasticity estimates among users, following the recommendations from (Bellemare and Wichman 2020). The standard errors in all tables are robust to misspecification.

5.3.1 Rural Ghana

5.3.1.1 Household Demand for Fertilizer Use

Key results for the decision to use and intensity fertilizer demand by rural households both in the north and south of Ghana are shown in Columns 1 and 2 of Tables 6 and 7. Elasticity estimates in these columns suggest a negative and significant own-price elasticity of fertilizer use among all rural households in Ghana. Also, column 1 of Table 6 indicates that for rural households in northern Ghana, the elasticity of the likelihood of fertilizer use with respect to agricultural wage is approximately 0.25%, which is statistically significant at the 10% level. However, conditional on fertilizer use, agricultural wage has no significant impact on the quantity of fertilizer use. On the other hand, for households in southern Ghana, the elasticity of the likelihood of fertilizer use with respect to agricultural wage is approximate -0.2%, which is significant at the 5% level. But

[7] Due to over parameterization of my model arising from year by location fixed effect, I could not estimate Double-Hurdle using the single Stata syntax “dhreg”. Instead, I run two separate probit and truncated normal regression models.

once the decision to apply fertilizer has been made, agricultural wage has no significant effect on the intensity of fertilizer use. These results from columns 1 and 2 of Tables 6 and 7 suggest that labor and fertilizer may be substitutes for northern Ghana, while labor and fertilizer may be complements in the south. These results indicate that households in the north intensify fertilizer use as agricultural wage increases, consistent with Boserupian theory. At the same time, that is not the case among rural households in the south.

Again, column 1 of Table 6 also suggests that a percentage increase in land rental rates in northern reduces the likelihood and intensity of fertilizer use by approximately 0.5% and 0.15%, respectively, and these are significant at 1% and 10% levels, respectively. On the other hand, the elasticity of likelihood and intensity of fertilizer use with respect to land rental rate is -0.09% and 0.08%, respectively, among households in the south. These estimates are significant at 1% and 5%, respectively. These results show that in terms of the decision to use fertilizer, a household in the north is more responsive to land rental rate changes than those in the south. However, when the decision to use fertilizer has been made, land rental rates reduce the quantity of fertilizer use among household in the north but increases the likelihood of fertilizer use among household in the south, which is consistent with Boserupian input intensification.

5.3.1.2 Household Demand for Herbicide Use

Columns 1 and 2 of Tables 6 and 7 show how households in both the north and south of Ghana are intensifying herbicides in response to input prices. Elasticity estimates in these columns suggest a negative and significant own price elasticity of herbicide use among all rural households in Ghana. As shown in column 3 of Table 7, the elasticity of the decision to use herbicide with respect to agricultural wage is 0.3% among households in the south, which is significant at a 1% level. However, among rural households in the north, column 3 of Table 6 suggests that agricultural wage has no significant effect on the decision to use herbicide. This implies that households in the south are intensifying the use of herbicides as agricultural wage increases, which is consistent with Boserupian theory. However, among households in the north, this is not the case.

Again, column 3 of Table 7 suggests that among households in the south, a percentage increase in the land rental rates significantly reduces the likelihood of herbicide use by 0.14%. But once the decision to use herbicide has been made, a percentage increase in land rental significantly increases hectares of additional land rented by 0.04%. On the other hand, among households in the north, columns 3 and 4 of Table 6 suggest that land rental rates have no significant effect on both the decision and intensity to use herbicides.

5.3.1.3 Household Demand for Hired Labor

Column 5 of Table 7 suggests that among households in southern Ghana, a percentage increase in the price of herbicide significantly reduces the probability of hiring labor by 0.16%. This result is unexpected and challenging to interpret as households are expected to replace herbicides with labor in the weeding of their fields as herbicide price increases. However, among households in the north, columns 5 and 6 of Table 6 suggest herbicide price has no significant effect on the likelihood and intensity of hiring labor.

In addition, columns 5 and 6 of Tables 6 and 7 show that an increase in land rental rates significantly reduces the likelihood of hiring labor among all households in rural Ghana. This result may suggest that as land prices rise, labor and land may be complementary inputs among Ghanaian households, with other factors held constant. However, once the decision to hire agricultural labor has been made, land rental rates significantly increase the number of laborers hired among households in the south. Still, they have no significant effect on households in the north.

5.3.1.4 Household Demand for Land Rentals

Columns 7 of Table 6 reveal that fertilizer price negatively and significantly affects the likelihood of participating in the land rental market among households in the north. This is reasonable because farmers have no incentive to expand production by renting land if fertilizer prices are high. On the other hand, columns 7 and 8 of Table 7 suggest that fertilizer price has no significant effect on the likelihood and intensity of rented land among households in the south. Again, column 7 of Table 7 reveals that among households in the south, a percentage increase in the price of herbicide significantly reduces the likelihood of land rental by 0.19%. Similarly, column 7 of Table 6 also suggest that a percentage increase in herbicide price minimizes the intensity of rental land conditional on renting land among household in the north. Like in southern Ghana, farmers have no incentive to expand production by renting land if fertilizer prices are high.

5.3.2 Rural Nigeria

5.3.2.1 Household Demand for Fertilizer Use

Tables 8 and 9presents the results for DHM for factor inputs among rural households in Nigeria. Columns 1 and 2 of Tables 8 and 9 reveal a negative and significant own-price elasticity for fertilizer demand among all households in rural Nigeria. This negative own price elasticity for fertilizer is expected as it will be unprofitable for rural farmers to purchase more fertilizers as their price increases. Again, column 2 of Table 8 estimates that conditional on fertilizer use, the herbicide price significantly reduces the quantity of fertilizer use among households in the north. A plausible explanation could be that higher herbicide prices may correlate with a general lack of agro-dealers in the communities, hence a likely reduction in fertilizer use intensity. In contrast, columns 1 and 2 of Table 9 show that herbicide price has no significant effect on the likelihood and intensity of fertilizer use among households in the south.

For households in the north, columns 1 and 2 of Table 8 suggest that agricultural wages negatively and significantly affect the likelihood and intensity of fertilizer use. This could be because fertilizer application may be labor intensive, especially for commercial farms, reducing fertilizer application as wages increase. On the other hand, this is not the case for households in the south. Columns 1 and 2 of Table 9 reveal that agricultural wage has no significant impact on households' likelihood and intensity of fertilizer use. In addition, columns 1 and 2 of Table 8 suggests that the land rental rate has a positive and significant effect on both the probability and intensity of fertilizer use among household in the north, consistent with the Boserupian theory. Surprisingly, this phenomenon is quite the opposite among households in the south. Columns 1 and 2 of Table 9 show that the land rental rate negatively and significantly affects the decision to use fertilizer in the south. This is unexpected and difficult to interpret as farmers are more likely to intensify fertilizer use to expand production on existing farmlands as the land rental rate increases.

5.3.2.2 Household Demand for Herbicide Use

In column 3 of Table 8, a 1% increase in fertilizer price is less likely to reduce northern households' probability of participating in the herbicide market by 0.06%, which is significant at a 5% level. This result is similar to what Grabowski and Jayne (2016) observed in Zambia; herbicide use is more likely in areas with lower retail fertilizer prices. On the contrary, this phenomenon is quite the opposite among southern households- a 1% increase in fertilizer price increases the likelihood of herbicide use by 0.13%, which is significant at 10%. Again, Columns 3 and 4 of Tables 8 and 9 suggest that among all households in rural Nigeria, there is own price elasticity of herbicide use. This is expected as it would be unprofitable for rural farmers to purchase more herbicides as the price increases. As expected, among all households in rural Nigeria, columns 3 and 4 of Tables 8 and 9 show that as agricultural wage increases, rural farmers intensify the use of herbicides. This intensification is consistent with Boserupian theory and depicts how rural households may substitute capital for labor as agricultural wage increases. Another plausible explanation could be that households in rural Nigeria are likely to use labor-saving herbicides in clearing weeds on their fields when agricultural wage increases.

5.3.2.3 Household Demand for Hired Labor

In columns 6 and 7 of Tables 8 and 9, I find a positive elasticity of hired labor with respect to fertilizer price among all households in rural Nigeria. This result suggests that rural households are more likely to participate in the commercial labor market with a relatively increasing fertilizer price and decreasing agricultural wage. However, these elasticities are not statistically different from zero. Again, herbicide price negatively and significantly affects the likelihood of hiring labor among households in the south. This is entirely unexpected and difficult to explain. On the other hand, herbicide price has no significant effect on agricultural labor use among households in the north. As expected, own price elasticity of hired labor use is negative among all households in rural Nigeria. This is plausible since hiring more labor on farms would be unprofitable as wage increases. In addition, among northern households, a percentage increase in land rental rates significantly increases the likelihood and intensity of hired laborers by 0.05% and 0.097%, respectively. This is consistent with the Boserupian principle, and a possible explanation for this could be that in the presence of relative increasing land rental rates coupled with relative decreasing agricultural wages, households in the north are more likely to employ additional laborers to increase the yield on existing farmlands instead of renting additional hectares of land for expansion. Surprisingly, this relationship between land rental rates and hired labor use is the opposite in the south. Elasticity estimates of hired labor use with respect to land rental rate indicate that a land rental rate has a negative effect on the likelihood and intensity of hiring labor among households in the south. However, these elasticities are statistically not different from zero.

5.3.2.4 Household Demand for Land Rentals

Columns 7 and 8 of Table 8 reveal that fertilizer price positively and significantly affects the likelihood of participating in the land rental market among households in the south. This could be that as fertilizer price increases, household rent additional land to expand production. However, in the north, fertilizer price does not significantly affect leasing land. Again, among northern households, Columns 7 and 8 of Table 8 indicate that a percentage increase in the herbicide price positively and significantly impacts the likelihood of leasing land. However, once a participation decision has been made, a percentage increase in herbicide price reduces the hectares of leased land by 0.08%, and this estimate is significant at the 1% level. In the case of households in the south, this is quite different. In the south, column 7 of Table 9 suggests that the price of herbicides significantly reduces the likelihood of renting land by 0.3%. Results in Table 9, columns 7 and 8 also indicate that agricultural wage negatively and significantly affects the probability and intensity of leasing land in the south.

On the contrary, the agricultural wage does not significantly impact the probability and intensity of leasing land in the north. Lastly, columns 7 and 8 of Tables 8 and 9 indicate a negative own price elasticity of the likelihood of land rental use among all households in rural Nigeria. This is quite an expectation as an increase in rental rates will force farmers to demand less land in agricultural production due to high costs and, subsequently, low profits.

6.0 CONCLUSION AND POLICY IMPLICATION

The recent surge in the adoption of capital-using and labor-using inputs in different parts of Africa has prompted an interest in understanding whether farming systems are evolving in ways that are consistent with Boserup's theories of agricultural intensification. This paper uses repeated waves of nationally representative surveys from Ghana and Nigeria to establish the trends in input price ratios in both countries and then examines how households' use and intensity of fertilizer, herbicide, hired labor, and land rentals respond to changes in land, labor, fertilizer, and herbicide prices. Furthermore, this study investigates whether these relative price responses differ according to geographical location.

My preliminary results show that there are undoubtedly variations in the trends in factor pricing ratios between rural Ghana and Nigeria. While the agricultural wage rose faster relative to fertilizer and land prices in rural Ghana between 2009 and 2015, agricultural wages plummeted relatively in rural Nigeria between 2011 and 2019. A couple of reasons account for these relative input price trends between these two countries. Since 2000, Ghana has experienced a quick economic transformation and demographic change. Rural-to-urban and intra-rural migration have been prompted by rising off-farm pay rates. Therefore, off-farm employment is more likely to exert increasing pressure on rural wage rates in such areas.

On the contrary, Nigeria's economy has lagged behind Ghana's in terms of economic dynamism throughout the years, which has slowed the development of off-farm incomes. These factors and Nigeria's continuing population expansion have kept the country's agricultural labor supply relatively plentiful. Hence, agricultural wages are low compared to fertilizer and land prices. Boserupian intensification would posit that farmers will utilize labor and capital inputs more intensively as land becomes more scarce and costly.

In rural Ghana, my regression results show that, although input price ratio trends indicate that agricultural wage is rising faster than other inputs, I find that its effect on the adoption and intensity of capital-saving fertilizer and herbicide differs considerably among households in the north and south. For instance, according to these findings, rural households in the north increase their fertilizer usage as agricultural wages rise, which aligns with Boserupian theory. In contrast, rural households in the south are not experiencing this pattern.

On the contrary, results indicate that households in the south are intensifying the use of herbicides as agricultural wage rises, consistent with the Boserupian hypothesis. However, this is not the case in the north. Among households in the north, agricultural wage has no significant impact on the likelihood and intensity of herbicide use.

Furthermore, my regression results show that similar to the case in rural Ghana, the effect of input price on household demand for input differs considerably between the north and the south of Nigeria. For instance, Table 8's columns 1 and 2 reveal that, in line with the Boserupian theory, the land rental rate has a positive and significant impact on both the likelihood and the intensity of fertilizer use among households in the north. Surprisingly, southern households exhibit the opposite of this behavior. Table 9's columns 1 and 2 demonstrate that the land rental rate negatively and significantly impacts the decision to use fertilizer in the south. In contrast, a percentage increase in land rental rates significantly increases the likelihood and intensity of hired laborers by 0.05% and 0.097%, respectively. This is consistent with the Boserupian principle and could be because households in the north are more likely to employ additional laborers to increase the yield on existing farmlands. But in the south, the correlation between the cost of renting land and the employment of hired labor is the exact opposite. Despite some differences in input intensity between households in the north and south, as agricultural wage increases, all rural households in

Nigeria intensify the use of herbicides. This intensification is consistent with Boserupian theory and depicts how rural households may be substituting capital for labor.

Rural Ghana and Nigeria's results indicate that farmers intensify inputs partly but not entirely consistent with the Boserupian theory. These findings imply that households may have input use constraints that are systematically different, emphasizing the necessity for locally relevant policies or programs that allow households to respond more quickly and entirely to changes in factor price ratios (Kopper and Jayne 2019). In general, transaction costs and market imperfections in agricultural factor markets may partially explain why farmers cannot alter their proportions of land, labor, and capital inputs as relative factor prices change. Additionally, findings indicate that to increase ISFM adoption, significant investments in hyper-local agricultural R&D and bidirectional extension programs will be required, allowing ISFM promotion programs to be tailored to reflect regional differences in how agricultural factor price ratios and other economic incentives are changing (Jayne et al. 2019). Also, further work is needed to determine how government subsidy programs may influence input demand within a specific region. Lastly, additional work is required to examine whether the Boserupian input intensification theory holds for specific quintiles of household asset distribution; it is possible that wealthier households can respond to relative factor price changes to a greater extent and more rapidly than highly constrained resource-poor households.

APPENDICES

APPENDIX A:

Tables and Figures

Table 1 Trends in Selected Ag Input Use in Ghana and Nigeria between 1990 and 2019

	Tot. Avg. Fertilizer Use per area of cropland(kg/ha) a/		**Tot. Pesticide Use per area of cropland (kg/ha) a/**		**Tot Herbicide Use(ton) a/**		**Ag. Machinery per 100 sq. km of arable land b/**	
Year	Ghana	Nigeria	Ghana	Nigeria	Ghana	Nigeria	Ghana	Nigeria
1990	3.09	12.49	0.02	--	8	--	7.13	4.9
2000	1.96	4.57	0.01	--	22	--	4.92	5.54
2010	14.5	10.15	0.23	--	692	--	--	--
2019	35.84	16.95	1.86	--	6498	--	--	--

Sources: a/ FAOSTAT 2021. Total fertilizer use comprises of total Nitrogen(N), Phosphate(P205) and Potash(K20) nutrients. See more details at FAOSTAT. b/ constructed from World Bank data: World Development Indicators. -- indicates unavailability of data.

Table 2 Data Description for Selected Variables in Rural Ghana

Variables	Description of Variables
Dependent Variables:	
Demand for Commercial inorganic Fertilizer (kg)	Household's demand for commercial inorganic fertilizer - kilograms
Demand for Herbicides (litres)	Household's demand for commercial herbicide measured in litres. These includes all types of herbicides used by households on their farms
Demand for Hired Labor (number)	Household's demand for hired labor measure by the number of men/women households hired during the major planting season. This excludes family labor.
Demand for Land rentals (ha)	Households demand for land rentals measured in hectares during the major planting season
Independent Variables:	
Price of Fertilizer (cedis/kg)	Price of commercial inorganic fertilizer per kilos during the major planting season (cedis/kg)
Price of Herbicides (cedis/litre)	Price of commercial herbicide per litre during the major planting season (cedis/L)
Agricultural Wage (cedis/day)	The agricultural wage per day paid to hired laborers during the major planting season. This includes work done in all aspect to farming like clearing, harvesting etc.
Price of Farmland (cedis/ha)	The price per hectares of rented farmland during the major season
Output Price (cedis/kg)	The price per kg of cocoa, cassava, and maize
Male (1/0)	Sex of the Household Head (Male=1 Female=0)
Household size (number)	Size of the household measured as the number of people living in a particular household
Age of Household Head (years)	Age in years of the Household head.
Household Assets (cedis)	This represents the monetary value of all household durable assets like cars, bicycle, TVs, radio, farm machinery etc.
Population Density (pp/ha)	Population density at the district measured by persons per hectares
Land Holdings (ha)	The amount of land in hectares controlled and or owned by the household
Regional dummies	The 10 geographical regions in Ghana

Table 3 Data Description for Selected Variables Used in Rural Nigeria

Variables	Description of Variables
Dependent Variables:	
Demand for Commercial Fertilizer (NPK) (kg)	Household's demand for commercial inorganic fertilizer (NPK)- kg
Demand for Herbicides (litres)	Household's demand for commercial herbicide measured in litres. These includes all types of herbicides used by households on their farms
Demand for Hired Labor (number)	Household's demand for hired labor measure by the number of men/women households hired during the major planting season. This excludes family labor.
Demand for Land rentals (Ha)	Households demand for land rentals measured in hectares during the major planting season
Independent Variables:	
Price of Fertilizer (naira/kg)	Price of commercial fertilizer (NPK) per kilos during the major planting season (naira/kg)
Price of Herbicides (naira/L)	Price of commercial herbicide per litre during the major planting season (naira/L)
Agricultural Wage (naira/day)	The agricultural wage per day paid to hired laborers during the major planting season. This includes work done in all aspect to farming like clearing, harvesting etc.
Price of Farmland (naira/ha)	The price per hectares of rented farmland during the major season
Output Price (naira/kg)	The price per kg of sorghum, cassava, and maize
Male (1/0)	Sex of the Household Head (Male=1 Female=0)
Household size (number)	Size of the household measured as the number of people living in a particular household
Age of Household Head (years)	Age in years of the Household head.
Household Assets (000' naira)	This represents the monetary value of all household durable assets like cars, bicycle, TVs, radio, farm machinery etc.
Population Density (pp/ha)	Population density at the Local Government Level measured by persons per hectares
Land Holdings (ha)	The amount of land in hectares controlled and or owned by the household
Distance to nearest market (km)	The distance in kilometers between the nearest market and the Household dwellings
Plot slopes (%)	The slope of the plot measured in percentage
Zonal dummy (1=north east)	The geographical zones in Nigeria categorized by North-central, North-east, North-west, South-south, South-east and South-west

Table 4 Descriptive Statistics of Variables Used in Rural Ghana

	Wave 1 (2009/10)					Wave 2 (2014/15)				
	Value at ith Perc. In Distr.					Value at ith Perc. In Distr.				
Variables	25th	50th	75th	90th	Mean	25th	50th	75th	90th	Mean
Dependent Variables										
Demand for inorganic Fertilizer (Kg)	0	0	0	50	11	0	0	0	100	14.4
Demand for Herbicides (liters)	0	0	0	2	0.63	0	0	0	4	0.9
Demand for Hired Labor	0	4	12	21	7	0	0	5	15	3.8
Demand for Land Rentals (Ha)	0	0	0	1.6	0.25	0	0	0	1.6	0.24
Independent Variables										
Price of Fertilizer (Cedis/kg)	1	1.7	2.3	7	3.47	1.19	2	3.3	4	2.6
Price of Herbicide (Cedis/L)	11.9	13.6	15.7	20.4	14.3	9	10.5	15	32.5	15.8
Agricultural Wage (Cedis/day)	3.5	6.5	9.6	13.6	8.4	8	11	16.6	24	16.2
Price of Farmland (Cedis/Ha)	9.5	44.7	63.1	109.4	116.5	39.2	67	97	101	81
Price of Maize (Cedis/kg)	0.21	0.5	0.75	1	0.58	0.33	0.68	1.05	1.6	0.82
Price of Cocoa (Cedis/kg)	2.4	2.43	2.76	2.76	2.6	0.6	0.84	2.11	4.3	1.53
Price of Cassava (Cedis/kg)	0.16	0.33	0.37	0.5	0.59	0.1	0.24	0.4	0.8	0.33
Male (1/0)	1	1	1	1	0.78	1	1	1	1	0.76
Household size (unit)	3	4	6	8	4.5	2	4	6	8	4.35
Age of Household Head (years)	36	46	59	70	48.1	40	50	62	74	51.6
Household Assets (cedis)	193	478	1205	2786	1302	482	1289	3320	8289	3911
Population Density (persons/ha)	0.28	0.38	0.45	0.93	0.5	0.26	0.37	0.52	0.73	0.48
North (1/0)	0	1	1	1	0.72	0	1	1	1	0.72
Land Holdings (ha)	1.01	2.02	3.6	6.2	3.1	0.8	1.6	3.2	6.06	3.12

Note: Prices are in real values (2014/15)

Table 5 Descriptive Statistics of Variables Used in Rural Nigeria

	Wave 1 (2011/12)					Wave 2 (2012/13)					Wave 3 (2015/16)					Wave 4 (2018/19)				
	Value at ith Perc. In Distr.					Value at ith Perc. In Distr.					Value at ith Perc. In Distr.					Value at ith Perc. In Distr.				
Variables	25th	50th	75th	90th	Mean	25th	50th	75th	90th	Mean	25th	50th	75th	90th	Mean	25th	50th	75th	90th	Mean
Depedent Variables																				
Demand for inorganic Fertilizer (NPK) (Kg)	0	0	30	150	37.3	0	0	40	250	50	0	0	10	150	33	0	0	50	150	41
Demand for Herbicides (liters)	0	0	0	7	1.5	0	0	0	7	1.5	0	0	2	6	1.6	0	2	6	12	3.5
Demand for Hired Labor (number)	0	0	4	10	3.16	0	6	13	23	8.1	3	9	18	24	10.6	2	9	21	26	11.1
Demand for Land Rentals (Ha)	0	0	0	0	0.03	0	0	0	0	0.03	0	0	0	0	0.02	0	0	0	0.12	0.04
Independent Variables																				
Price of fertilizer (Naira/kg)	156	204	240	288	304.8	174	193	221	250.9	195	151	172	196	302	295	138	150	160	190.5	157
Price of Herbicide (Naira/L)	420	852.4	2360	3173	1325	1447	1592	1930	2316	1819	1359	1510	1586	1812	1535	1325	1500	1600	1850	1500
Agricultural Wage (Naira/day)	960	1800	3870	7200	3123	965	1688	3860	5790	2313	755	1132	1510	2114	1172	958	1158	1560	2000	1280
Price of Farmland (Naira/Ha)	3466	11861	57142	126315	183397	5722	18424	44634	98046	36815	9683	22434	63586	135658	52916	7304	14341	30888	71454	25838
Price of Maize (Naira/kg)	34	41.5	50	100	50	43	50	60	106	55	40	60	100	140	71	46	70	82	120	72
Price of Sorghum(Naira/kg)	40	45	47.5	78.5	50	60	61	62.5	90	65.8	71.6	80	100	140	85.7	80	80	85	109.5	83.7
Price of Cassava (Naira/kg)	30	34.7	48	100	65	20	21.3	24	48	32.9	31.6	34	48	75	45	35	40	60	70	44.2
Male (1/0)	1	1	1	1	0.88	1	1	1	1	0.88	1	1	1	1	0.84	1	1	1	1	0.8
Household size (number)	4	6	8	11	6.2	5	7	9	11	6.8	6	8	10	12	7.9	6	8	11	14	8.4
Age of Household Head (years)	31	50	60	70	50	40	50	62	72	50	43	52	63	72	52	45	54	65	74	54
Household Assets (000' naira)	9.7	24	60.5	113	65.3	13.7	33	69.7	123.9	62.5	12.7	30	64	120	81.6	17.5	46.2	104	182	94.8
Population Density (persons/ha)	1.8	4.2	10.9	31.8	13.1	2.5	4.8	12.5	28	12	3.3	5.7	12.5	27.4	13.1	6.6	16.7	33.4	51	21.2
Land Holdings (ha)	0.26	0.98	2.4	5.4	11.7	0.31	0.89	2.42	5.2	4.9	2.6	10.5	19.2	37.8	14.4	1.12	3.02	19.6	39	13.1
Distance to nearest market (km)	44.2	63.8	95.2	125.4	71.6	43.6	62.8	94.5	125	70.6	44.1	63.6	94.3	125.8	71.2	44.1	70	101.7	126	74.1
Plot slopes (%)	1.62	2.44	3.7	5.8	3.17	1.59	2.39	3.58	5.96	3.15	0	1.75	3.49	5.24	2.28	0	1.75	3.49	5.24	2.15
Zonal dummy (1=North East)	2	3	4	5	3	2	3	4	5	2.99	2	3	4	5	3	2	3	4	5	2.9

Note: Prices are in real values (2018/19)

Table 6 Double Hurdle Model Estimates for Factor Demands in Northern Ghana

Variables	Hurdle 1 Probability of participating in commercial inorganic fertilizer (Kg) Arcsinh (fertilizer demand) Probit Estimator	Hurdle 2 Demand for commercial fertilizer (NPK) upon participation Arcsinh (fertilizer demand) Truncated Normal Estimator	Hurdle 1 Probability of participating in commercial Herbicides (litres) Arcsinh (hericide demand) Probit Estimator	Hurdle 2 Demand for commercial Herbicides (litres) upon participation Arcsinh (hericide demand) Truncated Normal Estimator	Hurdle 1 Probability of participating in commercial labor. Arcsinh (hired labor demand) Probit Estimator	Hurdle 2 Demand for commercial labor upon participation Arcsinh (hired labor demand) Truncated Normal Estimator	Hurdle 1 Probability of participating Land rental market Arcsinh (land rental Probit Estimator	Hurdle 2 Demand for land rentals upon participation Arcsinh (land rental demand) Truncated Normal Estimator
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Arcsinh(Price of Fertilizer (Cedis/Kg))	-0.794***	-0.565***	0.185***	0.0279**	-0.109***	-0.0553	-0.179***	0.0175
	(0.0751)	(0.157)	(0.0653)	(0.0141)	(0.0355)	(0.0367)	(0.0553)	(0.0118)
Arcsinh(Price of Herbicides (Cedis/Litre))	0.0995**	0.00332	-1.445***	-0.194**	-0.0333	-0.0101	-0.102	-0.0642***
	(0.0476)	(0.0299)	(0.156)	(0.0856)	(0.0396)	(0.0366)	(0.0685)	(0.0206)
Arcsinh(Agricultural Wage (Cedis/Day))	0.254*	-0.0703	0.599	-0.115	0.0255	-0.0148	-0.611	-0.128
	(0.150)	(0.181)	(0.369)	(0.0898)	(0.140)	(0.124)	(0.476)	(0.125)
Arcsinh(Price of land rentals (Cedis/Ha))	-0.586***	-0.150*	-0.0185	0.0232	-0.742***	-0.0492	0.407**	-0.130**
	(0.0982)	(0.0873)	(0.108)	(0.0281)	(0.0737)	(0.0996)	(0.176)	(0.0512)
Arcsinh(Price of Maize(Cedis/Kg))	-0.0191	-0.237**	-0.578**	-0.0946	0.110	0.0870	0.155	-0.199***
	(0.178)	(0.0999)	(0.256)	(0.0709)	(0.139)	(0.111)	(0.253)	(0.0598)
Arcsinh(Price of Cocoa (Cedis/Ha))	0.691*	0.201	0.488	-0.321***	0.632**	-0.148	-0.979**	0.0412
	(0.382)	(0.137)	(0.317)	(0.0527)	(0.301)	(0.446)	(0.449)	(0.116)
Arcsinh(Price of Cassava (Cedis/Ha))	1.591***	-0.000325	4.318***	0.0446	0.456	0.741*	-0.607	-0.113
	(0.588)	(0.244)	(1.124)	(0.162)	(0.579)	(0.430)	(0.869)	(0.195)
HH. Assets Quintile Distr.								
2nd	0.0627	0.0461	0.149	-0.104	0.152	-0.0613	0.280	0.0554
	(0.145)	(0.177)	(0.304)	(0.141)	(0.120)	(0.129)	(0.241)	(0.0771)
3rd	0.376***	0.227	0.294	-0.134	0.507***	-0.00155	0.309	0.106
	(0.143)	(0.160)	(0.299)	(0.131)	(0.122)	(0.130)	(0.230)	(0.0738)
Arcsinh(Poulation Density (Persons/Ha)	0.529	-0.147	-3.178***	-0.206	0.349	0.171	2.084**	-0.219
	(0.480)	(0.486)	(0.813)	(0.260)	(0.409)	(0.393)	(0.847)	(0.234)
Arcsinh(Land Holdings (Ha)	0.128***	0.0599	0.100***	0.0618*	0.152***	0.171***	0.282***	0.284***
	(0.0436)	(0.0427)	(0.0383)	(0.0370)	(0.0329)	(0.0525)	(0.0304)	(0.0211)
Intercept	-2.308***	4.651***	0.614	2.825***	-0.513	3.000***	-0.217	0.666**
	(0.700)	(0.529)	(0.873)	(0.302)	(0.569)	(0.779)	(1.090)	(0.280)
Observation	1,331	315	921	112	1,331	465	956	435

Notes: Robust Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Variables included are Age of HH head, size of HH, indicator for whether HH head is male (1/0), Year FE, Regional FE, and interaction term (Year)x(Region). All prices are adjusted to 2014 prices using CPI from the World Bank data. There was no market access condition variable in the data, but we argue that the interaction term between Year and regional dummies can soak some of the bias caused by lack of a market access variable in the regression.

Table 7 Double Hurdle Model Estimates for Factor Demands in Southern Ghana

Variables	Hurdle 1 Probability of participating in commercial inorganic fertilizer (Kg)	Hurdle 2 Demand for commercial fertilizer (NPK) upon participation	Hurdle 1 Probability of participating in commercial Herbicides (litres)	Hurdle 2 Demand for commercial Herbicides (litres) upon participation	Hurdle 1 Probability of participating in commercial labor.	Hurdle 2 Demand for commercial labor upon participation	Hurdle 1 Probability of participating Land rental market	Hurdle 2 Demand for land rentals upon participation
	Arcsinh (fertilizer demand)	Arcsinh (fertilizer demand)	Arcsinh (hericide demand)	Arcsinh (hericide demand)	Arcsinh (hired labor demand)	Arcsinh (hired labor deman	Arcsinh (land rental demand)	Arcsinh (land rental demand)
	Probit Estimator	Truncated Normal Estimator	Probit Estimator	Truncated Normal Estimator	Probit Estimator	Truncated Normal Estimator	Probit Estimator	Truncated Normal Estimator
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Arcsinh(Price of Fertilizer (Cedis/Kg))	-0.380***	-0.808***	0.147***	0.0131	-0.00426	-0.0131	0.0139	0.000760
	(0.0435)	(0.0743)	(0.0375)	(0.0126)	(0.0214)	(0.0184)	(0.0266)	(0.00894)
Arcsinh(Price of Herbicides (Cedis/Litre))	-0.0258	0.0770*	-1.303***	-0.135***	-0.162***	-0.0219	-0.195***	0.00111
	(0.0329)	(0.0421)	(0.0583)	(0.0313)	(0.0236)	(0.0181)	(0.0332)	(0.0131)
Arcsinh(Agricultural Wage (Cedis/Day))	-0.188**	-0.142	0.320***	-0.0586	-0.00870	-0.0953**	0.00756	0.114**
	(0.0845)	(0.126)	(0.0901)	(0.0508)	(0.0555)	(0.0426)	(0.0692)	(0.0449)
Arcsinh(Price of land rentals (Cedis/Ha))	-0.0907***	0.0838**	-0.139***	0.0397***	-0.326***	0.0518***	0.322***	0.00591
	(0.0260)	(0.0397)	(0.0287)	(0.0120)	(0.0171)	(0.0154)	(0.0229)	(0.0133)
Arcsinh(Price of Maize(Cedis/Kg))	0.144	-0.278**	0.553***	-0.0504	0.155*	-0.108	-0.0988	-0.0135
	(0.122)	(0.127)	(0.134)	(0.0560)	(0.0804)	(0.0699)	(0.0999)	(0.0440)
Arcsinh(Price of Cocoa (Cedis/Ha))	-0.169*	-0.117	-0.644***	-0.0634	-0.441***	-0.0856	-0.0746	-0.0512**
	(0.0912)	(0.125)	(0.107)	(0.0432)	(0.0733)	(0.0680)	(0.0862)	(0.0248)
Arcsinh(Price of Cassava (Cedis/Ha))	0.664***	0.169	0.706***	0.0978	0.419***	0.292**	0.439**	0.0640
	(0.208)	(0.222)	(0.245)	(0.0898)	(0.152)	(0.117)	(0.193)	(0.0793)
HH. Assets Quintile Distr.								
2nd	0.208**	0.151	0.235**	-0.00885	0.242***	0.0878*	0.139	0.0432
	(0.0974)	(0.136)	(0.115)	(0.0563)	(0.0619)	(0.0530)	(0.0876)	(0.0503)
3rd	0.322***	0.282**	0.348***	0.0512	0.300***	0.132**	-0.0178	0.117**
	(0.108)	(0.139)	(0.133)	(0.0599)	(0.0726)	(0.0639)	(0.0977)	(0.0511)
Arcsinh(Poulation Density (Persons/Ha))	0.00242	-0.0903	-0.571***	0.0756	0.0764	-0.163**	-0.374***	-0.0878
	(0.119)	(0.126)	(0.139)	(0.0753)	(0.0755)	(0.0811)	(0.0898)	(0.0592)
Arcsinh(Land Holdings (Ha)	0.160***	0.108**	0.115***	0.106***	0.267***	0.188***	0.340***	0.342***
	-0.0331	(0.0532)	(0.0246)	(0.0205)	(0.0325)	(0.0249)	(0.0159)	(0.0136)
Intercept	-0.223	5.258***	3.796***	2.160***	1.108***	2.519***	-1.853***	0.238
	(0.361)	(0.627)	(0.419)	(0.229)	(0.257)	(0.229)	(0.361)	(0.324)
Observation	3,350	252	3,350	444	3,350	1,424	3,350	990

Notes: Robust Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Variables included are Age of HH head, size of HH, indicator for whether HH head is male (1/0), Year FE, Regional FE, and interaction term (Year)x(Region). All prices are adjusted to 2014 prices using CPI from the World Bank data. There was no market access condition variable in the data, but we argue that the interaction term between Year and regional dummies can soak some of the bias caused by lack of a market access variable in the regression.

Table 8 Double Hurdle Model Estimates for Factor Demands in Northern Nigeria

Variables	Hurdle 1 Probability of participating in commercial fertilizer (NPK) Kg Arcsinh (fertilizer demand) Probit Estimator	Hurdle 2 Demand for commercial fertilizer (NPK) upon participation; Arcsinh (fertilizer demand) Truncated Normal Estimator	Hurdle 1 Probability of participating in commercial Herbicides (litres) Arcsinh (hericide demand) Probit Estimator	Hurdle 2 Demand for commercial Herbicides (litres) upon participation; Arcsinh (hericide demand) Truncated Normal Estimator	Hurdle 1 Probability of participating in hired labor Arcsinh (hired labor demand) Probit Estimator	Hurdle 2 Demand for hired labor upon participation; Arcsinh (hired labor demand) Truncated Normal Estimator	Hurdle 1 Probability of participating Land rental market Arcsinh (land rental Probit Estimator	Hurdle 2 Demand for land rentals upon participation; Arcsinh (land rental demand) Truncated Normal Estimator
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Arcsinh(Fertilizer Price (Naira/Kg))	-0.338***	-0.377***	-0.0681**	0.0114	0.0235	0.000327	0.0140	0.0136
	(0.0297)	(0.0389)	(0.0267)	(0.0215)	(0.0261)	(0.0184)	(0.0301)	(0.0114)
Arcsinh(Herbicides Price (Naira/Litre)	0.00485	-0.139***	-0.417***	-0.0903***	-0.00564	0.0358	0.152***	-0.0813***
	(0.0352)	(0.0422)	(0.0399)	(0.0339)	(0.0335)	(0.0245)	(0.0401)	(0.0149)
Arcsinh(Agricultural Wage (Naira/Day	-0.0687***	-0.0913***	0.138***	0.0529***	-0.132***	-0.00647	-0.00391	-0.00764
	(0.0208)	(0.0317)	(0.0212)	(0.0189)	(0.0216)	(0.0149)	(0.0250)	(0.00783)
Arcsinh(Price of Land Rentals (Naira/I	0.0853***	0.0799**	-0.140***	-0.0293	0.0554**	0.0979***	0.0101	-0.0482***
	(0.0235)	(0.0361)	(0.0230)	(0.0187)	(0.0228)	(0.0174)	(0.0269)	(0.0108)
Arcsinh(Maize Price (Naira/Kg)	-0.135***	0.150**	0.0644	-0.0444	0.0670	0.0397	0.0233	-0.0331*
	(0.0453)	(0.0717)	(0.0430)	(0.0326)	(0.0413)	(0.0313)	(0.0483)	(0.0176)
Arcsinh(Sorghum Price (Naira/Kg)	-0.0617	-0.0329	-0.0625	-0.0637*	-0.160***	-0.0145	-0.213***	-0.0252
	(0.0486)	(0.0609)	(0.0458)	(0.0339)	(0.0469)	(0.0355)	(0.0517)	(0.0183)
Arcsinh(Cassava Price (Naira/Kg)	0.0669	0.201***	-0.0475	-0.0685*	-0.0229	0.121***	0.133***	0.0539**
	(0.0436)	(0.0741)	(0.0433)	(0.0350)	(0.0416)	(0.0333)	(0.0495)	(0.0214)
HH. Assets Quintile Distr.								
2nd	0.268***	-0.00964	0.172***	0.0602	0.199***	0.111***	0.105*	0.0193
	(0.0471)	(0.0654)	(0.0480)	(0.0435)	(0.0442)	(0.0342)	(0.0561)	(0.0197)
3rd	0.438***	0.142**	0.344***	0.116***	0.410***	0.231***	0.0226	0.0442**
	(0.0501)	(0.0665)	(0.0506)	(0.0429)	(0.0484)	(0.0361)	(0.0611)	(0.0219)
Arcsinh(Poulation Density (Persons/Ha	0.0342	0.0354	-0.0919***	-0.0347	0.131***	-0.00742	0.127***	-0.0788***
	(0.0243)	(0.0334)	(0.0247)	(0.0218)	(0.0236)	(0.0170)	(0.0303)	(0.0120)
Arcsinh(Land Holdings (Ha)	0.0662***	0.0332**	0.0712***	0.0181*	0.0804***	0.0654***	0.179***	0.443***
	(0.0111)	(0.0145)	(0.0113)	(0.00942)	(0.0106)	(0.00904)	(0.0127)	(0.0121)
Intercept	0.573	6.057***	2.130***	2.875***	-0.861*	0.234	-2.404***	-2.328***
	(0.539)	(0.744)	(0.544)	(0.427)	(0.509)	(0.391)	(0.595)	(0.263)
Observation	5,365	1,767	5,365	1,752	5,365	3,214	5,365	4,171

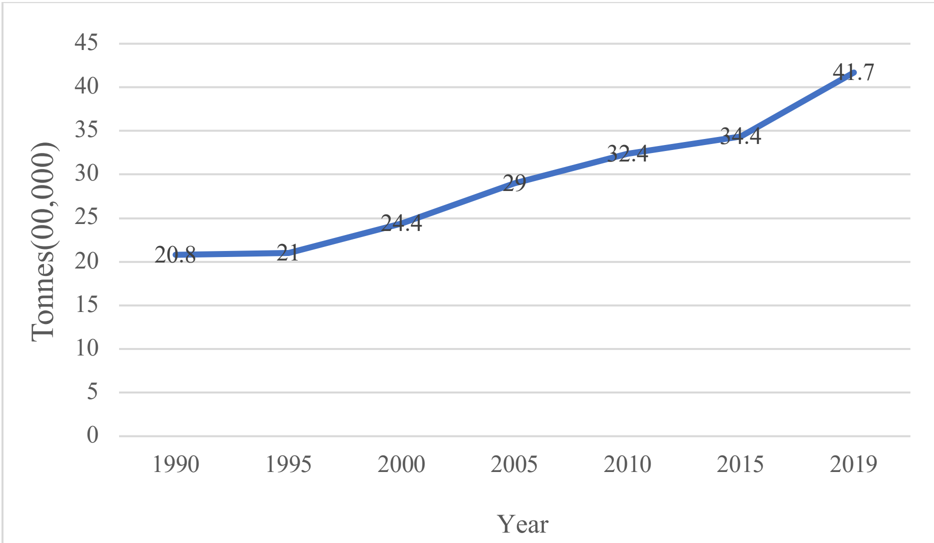
Notes: Robust Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Variables included are Age of HH head, size of HH, distance in km to nearest market, percentage of plot slope, indicator for whether HH head is male (1/0), Year FE, Zonal FE, and interaction term (Year)x(Zones). All prices are adjusted to 2018 prices using CPI from the World Bank data.

Table 9 Double Hurdle Model Estimates for Factor Demands in Southern Nigeria

	Hurdle 1 Probability of participating in commercial fertilizer (NPK) Kg	Hurdle 2 Demand for commercial fertilizer (NPK) upon participation;	Hurdle 1 Probability of participating in commercial Herbicides (litres)	Hurdle 2 Demand for commercial Herbicides (litres) upon participation;	Hurdle 1 Probability of participating in hired labor	Hurdle 2 Demand for hired labor upon participation;	Hurdle 1 Probability of participating Land rental market	Hurdle 2 Demand for land rentals upon participation;
	Arcsinh (fertilizer demand)	Arcsinh (fertilizer demand)	Arcsinh (hericide demand)	Arcsinh (hericide demand)	Arcsinh (hired labor demand)	Arcsinh (hired labor demand)	Arcsinh (land rental	Arcsinh (land rental demand)
Variables	Probit Estimator	Truncated Normal Estimator	Probit Estimator	Truncated Normal Estimator	Probit Estimator	Truncated Normal Estimator	Probit Estimator	Truncated Normal Estimator
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Arcsinh(Fertilizer Price (Naira/Kg))	-0.275***	-0.505***	0.134*	-0.0828	0.0248	0.000432	0.144**	-0.0368
	(0.0645)	(0.0816)	(0.0707)	(0.169)	(0.0561)	(0.0448)	(0.0701)	(0.0413)
Arcsinh(Herbicides Price (Naira/Litre)	-0.00972	-0.233	-0.617***	-0.263**	-0.217***	-0.0414	-0.333***	0.0541
	(0.0811)	(0.179)	(0.0854)	(0.110)	(0.0678)	(0.0542)	(0.0997)	(0.0423)
Arcsinh(Agricultural Wage (Naira/Day	-0.0611	-0.105	0.108*	0.130*	-0.230***	-0.0904***	-0.145***	-0.0332*
	(0.0425)	(0.0824)	(0.0553)	(0.0764)	(0.0505)	(0.0309)	(0.0475)	(0.0199)
Arcsinh(Price of Land Rentals (Naira/I	-0.0694**	-0.00972	-0.0565	-0.0259	-0.0253	-0.0182	-0.00565	-0.0435**
	(0.0283)	(0.0536)	(0.0356)	(0.0504)	(0.0252)	(0.0220)	(0.0349)	(0.0181)
Arcsinh(Maize Price (Naira/Kg)	0.199***	-0.119	-0.0640	-0.146**	-0.000488	-0.00183	-0.188***	0.0423*
	(0.0465)	(0.105)	(0.0545)	(0.0632)	(0.0386)	(0.0326)	(0.0494)	(0.0249)
Arcsinh(Sorghum Price (Naira/Kg)	-0.258	5.145***	0.771*	0.909**	1.626***	0.888***	1.009***	0.313*
	(0.475)	(0.477)	(0.401)	(0.393)	(0.282)	(0.231)	(0.273)	(0.180)
Arcsinh(Cassava Price (Naira/Kg)	0.0932	0.0396	0.138**	-0.0674	0.0890*	0.148***	-0.267***	-0.0282
	(0.0601)	(0.105)	(0.0636)	(0.111)	(0.0474)	(0.0388)	(0.0603)	(0.0271)
HH. Assets Quintile Distr.								
2nd	0.232***	0.252*	-0.00253	0.128	-0.0664	-0.0288	0.0261	0.0243
	(0.0798)	(0.129)	(0.0962)	(0.122)	(0.0657)	(0.0520)	(0.0840)	(0.0435)
3rd	0.293***	0.302**	0.0721	0.0867	-0.104	0.130**	-0.0701	0.0649
	(0.0804)	(0.128)	(0.0921)	(0.109)	(0.0634)	(0.0509)	(0.0812)	(0.0428)
Arcsinh(Poulation Density (Persons/Ha	0.0527**	-0.0666	-0.131***	-0.0816**	-0.0583***	-0.0623***	0.0127	-0.0200
	(0.0225)	(0.0458)	(0.0268)	(0.0360)	(0.0183)	(0.0159)	(0.0237)	(0.0141)
Arcsinh(Land Holdings (Ha)	-0.00223	0.105***	0.0469***	0.0540**	0.0982***	0.0980***	0.158***	0.494***
	(0.0155)	(0.0395)	(0.0158)	(0.0243)	(0.0157)	(0.0124)	(0.0166)	(0.0176)
Intercept	1.814	-13.72***	-2.793	-0.124	-6.368***	-2.458*	1.136	-4.641***
	(2.348)	(3.097)	(2.164)	(2.860)	(1.575)	(1.275)	(1.745)	(0.993)
Observation	3,209	440	3,258	252	3,258	1,700	3,258	2,599

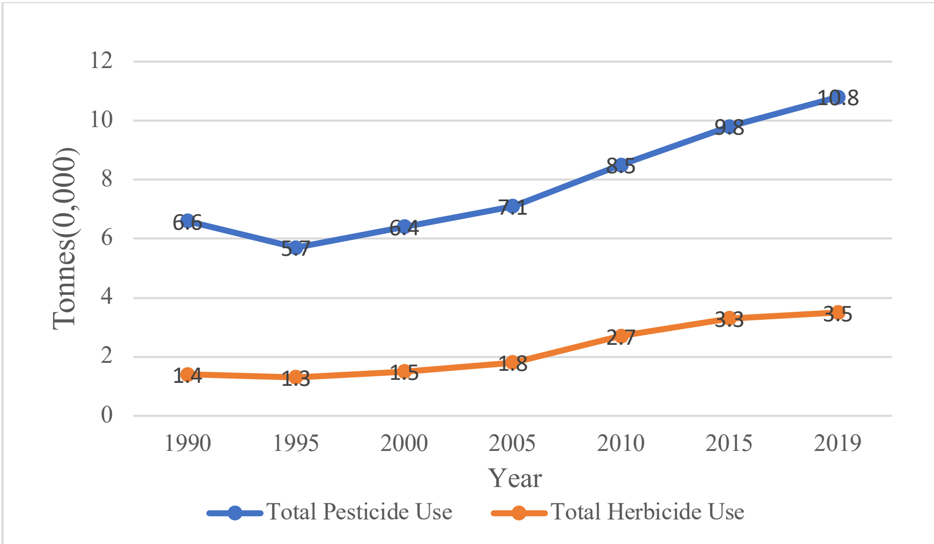
Notes: Robust Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Variables included are Age of HH head, size of HH, distance in km to nearest market, percentage of plot slope, indicator for whether HH head is male (1/0), Year FE, Zonal FE, and interaction term (Year)x(Zones). All prices are adjusted to 2018 prices using CPI from the World Bank data.

Figure 1 Total Fertilizer Use in Africa from 1990 to 2019



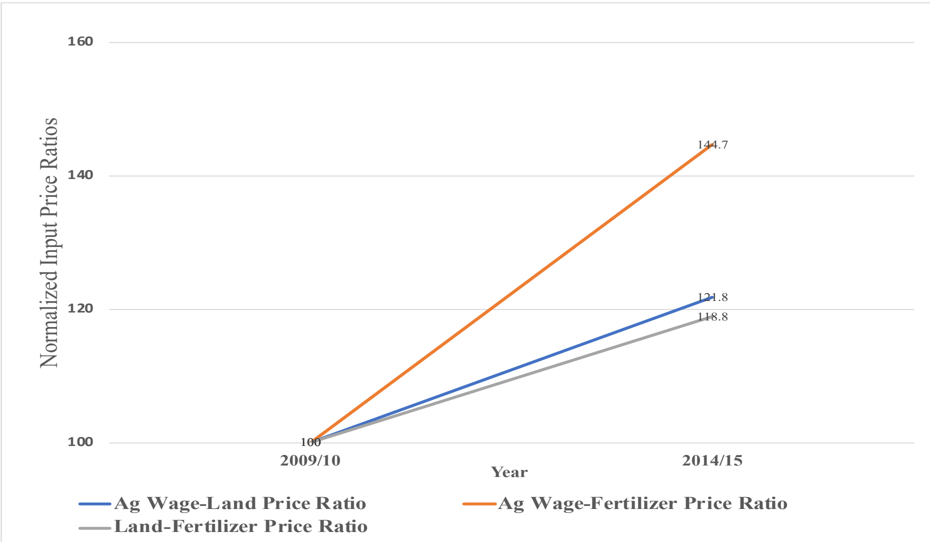
Source: FAOSTAT 2021

Figure 2 Total Pesticide and Herbicide Use in Africa from 1990 to 2019



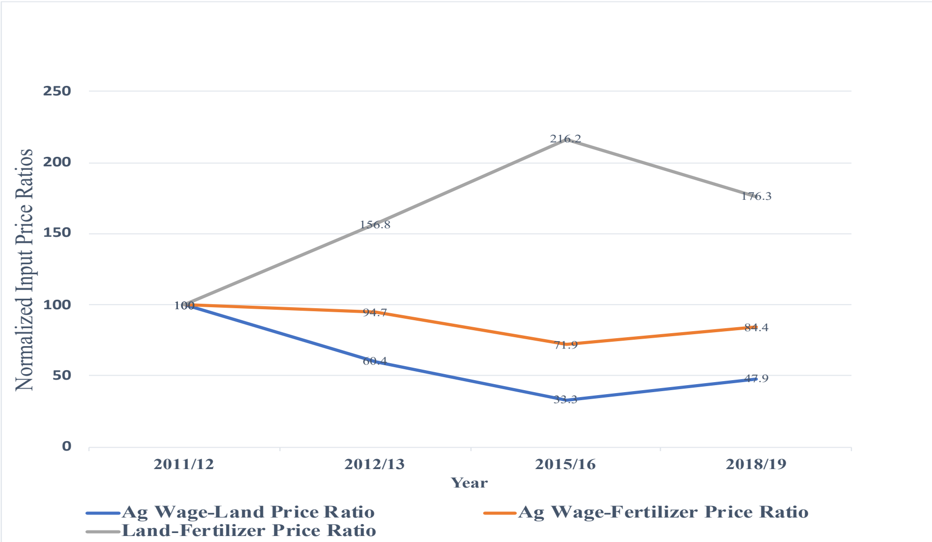
Source: FAOSTAT 2021

Figure 3 Relative Median Input Price Ratios in rural Ghana between 2009 and 2015



Source: Based on the author's calculation from the Ghana Socio-economic survey, waves 1&2
Note: Prices of inputs are constructed at the district level; district medians are then averaged to the national level. The price of land is measured in cedi per hectare (GHS/Ha), the price of fertilizer is estimated as cedi per kilograms (GHS/Kg), and agricultural wage is measured as cedi per day (GHS/day). The fertilizer price represents all commercial inorganic fertilizers (NPK, Urea, etc.) the household purchased during the major planting season

Figure 4 Relative Median Input Price Ratios in rural Nigeria between 2011 and 2019



Source: Based on the author's calculation from Nigeria's Living Standards and Measurement Survey-Integrated Survey on Agriculture (LSMS-ISA), waves 1,2,3 &4

Notes: Prices of inputs are constructed at the Local Government Area (LGA) level. The price of land is measured in naira per hectare (N/Ha), the price of fertilizer is measured as naira per kilograms (N/Kg), and agricultural wage is measured as naira per day (N/day). Fertilizer price is the price of commercial Nitrogen Phosphorus Potassium (NPK) fertilizers the household purchased during the major planting season.

APPENDIX B:

Deriving Elasticities from Arcsinh-Arcsinh Specification

I borrow extensively from Bellamare and Wichman (2019) to derive elasticities from an arcsinh-arcsinh specification.

For any variable y, let $y^* = \sinh^{-1}(x) = \ln(x + \sqrt{x^2 + 1})$ (9)

This implies that $\frac{\partial y*}{\partial y} = \frac{1}{\sqrt{x^2+1}}$ (10)

Now, consider a simple linear regression of the form;

$$y^* = \alpha + \beta x^* + \varepsilon \quad (11)$$

To recover y from the left-hand side of equation (11) after estimating it, I need to apply the sinh transformation on both sides of equation (11) so that,

$$y = \sinh(\hat{\alpha} + \hat{\beta} x^* + \hat{\varepsilon}) \quad (12)$$

$$\Rightarrow \quad \frac{\partial \hat{y}}{\partial x} = \frac{\hat{\beta}\cosh(\hat{\alpha}+\hat{\beta}\sinh^{-1}(x)+\hat{\varepsilon})}{\sqrt{x^2+1}} \quad (13)$$

So that the elasticity $\widehat{\xi_{yx}} = \frac{\hat{\beta}\cosh(\hat{\alpha}+\hat{\beta}\sinh^{-1}(x)+\hat{\varepsilon})}{\sqrt{x^2+1}} \cdot \frac{x}{y}$ (14)

But $y^* = \alpha + \beta x^* + \varepsilon$

So, I can write equation (6) as

$$\widehat{\xi_{yx}} = \frac{\hat{\beta}\cosh(\hat{\alpha}+\hat{\beta}\sinh^{-1}(x)+\hat{\varepsilon})}{\sqrt{x^2+1}} \cdot \frac{x}{y} = \hat{\beta} \cdot \frac{\sqrt{y^2+1}}{y} \cdot \frac{x}{\sqrt{x^2+1}} \quad (15)$$

Because $\lim_{x\to\infty} \frac{x}{\sqrt{x^2+1}} = 1$ and $\lim_{y\to\infty} \frac{\sqrt{y^2+1}}{y} = 1$, for large values of x and y,

$$\widehat{\xi_{yx}} \approx \hat{\beta}$$

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