Understanding fertilizer use and profitability for rice production across Nigeria's diverse agro ecological conditions[1]

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Abstract:

Despite a widely accepted view that increased inorganic fertilizer use is necessary for sustained productivity growth in sub Saharan Africa, there is limited empirical evidence of how actual fertilizer use rates compare to economically profitable levels. This study exploits the political economy of fertilizer access in Nigeria to identify the effects of nitrogen application on rice production in Nigeria and how this varies across agro various production and market constraints. We find that fertilizer use in Nigeria is not as low as conventional belief suggests and locations in close proximity to key political figures tend to have better access to fertilizer. Yield response to (and profitability of) applied nitrogen for rice in Nigeria varies significantly across different agro ecological conditions and over time. When the full cost of fertilizer acquisition is taken into consideration, the profitability of nitrogen application falls significantly, remaining profitable for a relatively small subset of rice farmers. While observed mean nitrogen application rates for rice tend to lie below the economically optimal levels for farmers with high marginal physical product of applied nitrogen, we find mean observed use rates higher than expected profit maximizing rates for farmers with poor yield response to applied nitrogen. Reducing transportation and other costs associated with fertilizer acquisition is likely to significantly increase the profitability and use of nitrogen among Nigerian rice farmers. However, this is not likely to be enough to sustainably increase farmer productivity as other constraints such as agro ecological conditions, timely access to the product, availability of complementary inputs and credit, as well as management practices are also needed.

Introduction

Fertilizer use in Africa is estimated to have stagnated at 6-12kg/ha/year for the last 10 years (Sommer et al., 2013; Monpellier 2013) and no African country is said to have been able to achieve the 50kg of nutrient per hectare use target set for 2015 at the Abuja fertilizer summit. (Sommeret al., 2013; Monpellier 2013). This has resulted in significant increases in effort and resource allocation to programs geared to increase farmers' use of improved technologies and consequently, their productivity. These efforts include high cost input subsidy programs usually involving fertilizer alone or along with other improved technologies.

Despite a widely accepted view that increased inorganic fertilizer use is necessary for sustained productivity growth, there is limited empirical evidence of how farmers' actual fertilizer use rates compare to economically profitable levels in Sub Saharan Africa (SSA). As far as we are aware, no studies on this issue currently exist in Nigeria and a study by Sheahan et al. (2013) remains an exception for maize in Kenya. Figures of extremely low general levels of fertilizer use continue to be cited despite likely variation across soil quality, farming practices and cropping systems. The profitability of fertilizer use (key to the adoption and sustained use of the product) is likely to vary significantly across agro ecological zones and major farming systems as farmers face different production constraints. This paper seeks to provide empirical evidence on the profitability of fertilizer use for rice production across Nigeria and how this correlates with fertilizer use rates.

Using the 2010/11 and 2012/13 Nigeria Living Standard Measurement Survey-Integrated Survey on Agriculture (LSMS-ISA) panel dataset - we explore the rice yield response to nitrogen application on farmer plots in Nigeria. We derive marginal and average products of nitrogen from production function estimates. We disaggregate these by farming systems, agro ecological zones, rice production potential and soil nutrient constraints in order to explore the effect of local level farming conditions. Using both plot and household level data, this study uses a Correlated Random Effects (CRE) model and a Control Function Approach (CFA) to address the endogeneity of the nitrogen application decision for crop production. We calculate the profitability of nitrogen application for rice and compare optimal and actual nitrogen application rates.

This paper contributes to the literature on fertilizer use in several ways. First, this is one of few studies that specifically addresses the endogeneity of fertilizer use in a production function framework. While various studies have explored the yield response of fertilizer in rice (and other crop) production, very few (none found in Nigeria) address the fact that there are likely unobserved characteristics that affect nitrogen application rates that also affect yields. Similarly, while there is evidence of yield response to fertilizer rates for different crops across sub Saharan Africa, there is limited empirical evidence on the profitability of fertilizer use across agro ecological conditions and how profitability correlates with actual fertilizer use rates. Sheahan et al. (2013) is an exception that considers how fertilizer use rates on maize in Kenya compare to expected profit maximizing use rates. We extend the approach of Sheahan et al. (2013) to address not only endogeneity of fertilizer use due to time invariant unobserved characteristics but also to address time varying unobserved factors[3].

Following the conventional belief of low fertilizer use in SSA, numerous policies geared to increase fertilizer use among farmers in SSA (to 50Kg per hectare of nutrients by 2015) have

[3] Sheahan et al (2013) only address the potential endogeneity due to time invariant unobserved factors.

taken off; particularly since the Abuja declaration in 2006. They include expensive programs like fertilizer and other input subsidies. As governments across SSA strive to increase farmer productivity and use of improved inputs such as fertilizer, it is necessary to understand the factors determining current fertilizer use rates. This will inform the areas and extent to which fertilizer use rates can be expected to respond to these strategies. This study explores if the conventional belief of low fertilizer use rates is supported by the empirical evidence from the LSMS-ISA. It compares observed use rates to expected profit maximizing quantities and discusses what factors are likely to explain observed patterns.

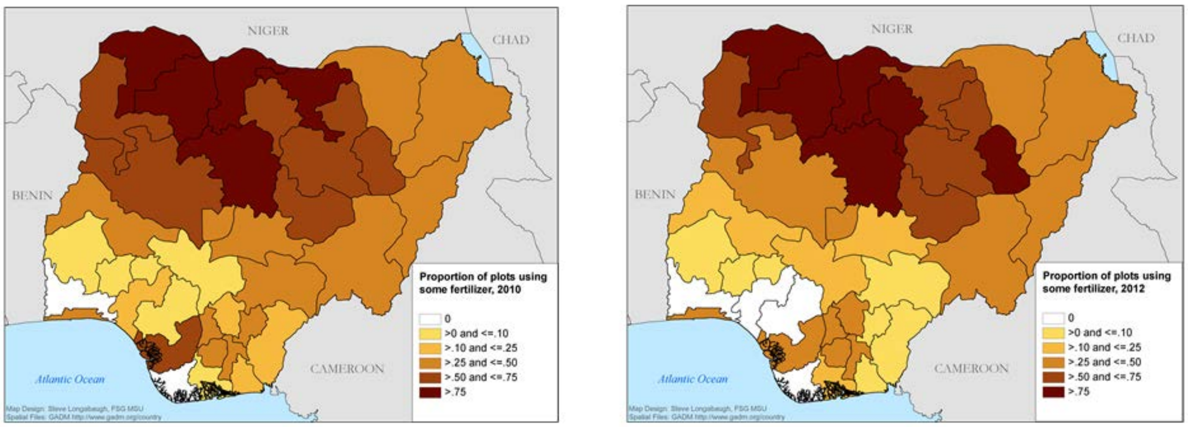
The rest of this paper is organized as follows: Section 2 describes fertilizer use generally, and then within rice production across Nigeria while Section 3 presents our conceptual framework and empirical methods. Section 4 describes our data. We present the production function estimates, marginal (and average) products and marginal (and average) value cost ratios for rice across various categorizations in section 5 and discuss these results. Section 6 concludes.

2.0 Fertilizer use across Nigeria

Since the 1940s, Nigerian governments have generally perceived that fertilizer use in the country was low. By the 1960s, population density had started rising and the government became increasingly concerned about farmers' awareness of fertilizer's benefits (Whetham 1966), and the effects of credit constraints (Ogunfowora and Norman, 1973). Since the 1970s, Nigerian governments have tried to stimulate fertilizer demand, grow the commercial fertilizer sector and lower fertilizer prices. Strategies used to stimulate fertilizer use include subsidies, using extension to develop soil fertility management technologies and programs to increase farmers' access to credit. These programs were said not to have significantly raised fertilizer demand (Nagy and Edun, 2002). Though programs continue to be developed, there is limited evidence that fertilizer use has increased substantially through even more recent programs such as the National Fadama Development Programs, National Special Programme for Food Security, and Presidential Initiatives on Agriculture (Liverpool-Tasie and Takeshima, 2013).

Despite the numerous factors cited as responsible for low fertilizer use, there is limited empirical evidence on the nature and rationale for the actual patterns of observed fertilizer use rates across Nigeria's diverse farming systems and cropping patterns. Fertilizer use and needs will vary across Nigeria depending on agro ecological conditions, market conditions, government policies, cropping systems and fertilizer responsiveness. Fertilizer use in the Northern states is typically higher than in the southern states (Figure 1). This is partly attributed to lower soil fertility (FFD, 2011; Smith et al. 1997), larger area cultivated and the growth of high value crops like cereals and vegetables in the region (Eboh et al., 2006). Additionally, Northern states have traditionally provided greater fertilizer subsidies since the colonial era when administrations provided support for fertilizer use out of concerns over soil depletion and desertification (Mustapha 2003).

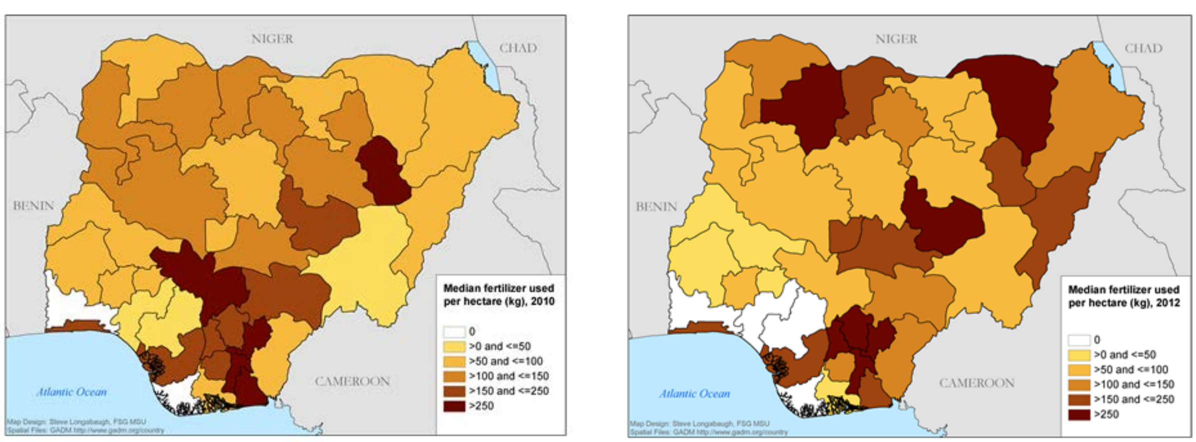
Figure 1: Fertilizer use across Nigeria 2010 and 2012: The percentage of plots on which fertilizer is applied



Source: Data generated by author from the 2010 and 2012 Living Standard Measurement Survey – Integrated Survey on Agriculture (LSMS) data and Map generated by Longabaugh, S. 2014

Fertilizer use rates across Nigeria are not as sparse as one may expect given nationally cited figures of 13kg per hectare. Figure 1 indicates that many farmers in Nigeria use some inorganic fertilizer and in many states, some inorganic fertilizer is applied on over 75% of plots. Conditional on use, fertilizer use rates vary significantly across space and time. (see figure 2). Fertilizer application rates are often greater than 100kg per hectare and while the general trend appears to be the maintenance or increase of input use rates between 2010 and 2012, some states, such as Kogi, Edo and Ondo (in Southern Nigeria) saw a decline in the median fertilizer use rates.

Figure 2: **Fertilizer use across Nigeria 2010 and 2012: Median quantity of fertilizer applied per hectare of land**[4]



Source: Data generated by author from the 2010 and 2012 Living Standard Measurement Survey – Integrated Survey on Agriculture (LSMS) data and Map generated by Longabaugh, S. 2014

[4] These are conditional values and states with 0 values have no record of fertilizer use among survey respondents.

2.1 Fertilizer use in rice production in Nigeria

Rice is one of the fastest growing commodities in Nigeria's food basket with likelihood of continued growth (Akande, 2003; USDA, 2014). The demand for rice has been increasing more rapidly in Nigeria compared to other West African countries. Since the 1970's, rice has increasingly become a major staple food for the Nigerian household in both urban and sub-urban areas of the country. This rapid increase in rice demand is largely due to rapid population growth, increased urbanization and people's preference for rice as a convenience food. According to Ayorinde et al. (2011), national demand for rice is estimated at 5 million metric tons of milled rice and rice consumption has increased from 3kg per capita in the 70s to over 25 kg currently. Along side this increasing demand, domestic production is estimated at about 3.2 million metric tons, creating a deficit of about 1.8 million metric tons of rice to meet local demand. This gap between domestic demand and supply of rice has left Nigeria highly dependent on rice importation and subject to price fluctuations on the world market. The recent hike in global cereal prices has seen significant effort within Nigeria to promote rice production and national self-sufficiency for rice. However, most of Nigeria's rice farmers are said to still rely on traditional technology with low use of modern inputs such as improved seed and inorganic fertilizer. Average rice yields in the country are low, ranging between 1 and 2.5 tons per hectare (Cadoni & Angelucci, 2013), against potential yields of 5-6 tons per hectare (Nwilene et al., 20).

Nigeria is endowed with favorable ecologies for rice cultivation. Various rice production systems and growing ecologies exist within Nigeria. They include: Upland (rain fed and irrigated), Hydromorphic, Rain fed Lowland, Irrigated Lowland, Deep Inland Water and Mangrove Swamp (Longtau, 2003). These production systems require different levels and types of inputs as well as management practices. There are also many different varieties of rice grown across these systems to address the peculiarities of the local growing conditions.

Fertilizer use from the 2010 and 2012 LSMS-ISA data for rice producers in Nigeria does not correspond to these figures. Average fertilizer use on rice (among rice producers who use some fertilizer) is about 230kg per hectare in 2010 and 225kg/ha in 2012. This is much higher than the national average fertilizer use cited as less than 13kg per hectare (FMARD, 2012; Banful et al., 2010) or about 6kg of nutrients per hectare (Takeshima et al., 2013; Liverpool-Tasie and Takeshima, 2013) [5].

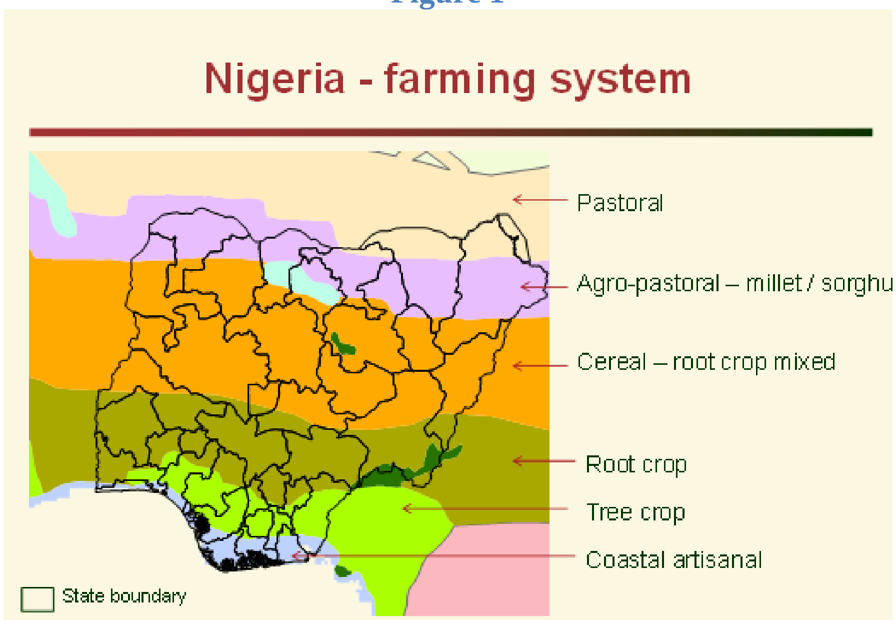
An important objective of this study is understanding the heterogeneity of fertilizer use and profitability across Nigeria's agro ecological zones, farming systems, rice production potential and soil nutrient constraints. Across agro ecological conditions, we categorize the rice farmers in our sample by agro ecological zones. According to the International Food Policy Research Institute (IFPRI) standardized agro ecological zone categorization (based on elevation and climatology), Nigeria falls into three agro ecological zones: tropic-warm/semiarid, tropic-warm/sub-humid and tropic-cool/sub-humid. Majority of rice production takes place in the

[5] Since these cited statistics are not conditional on use, we also calculate the unconditional fertilizer use and also find these to be much higher at 134.31kg and 142.99kg per hectare in 2010 and 2012 respectively. These translate to Nitrogen use rates of about 61.77kg and 65.78kg per hectare of Nitrogen assuming nitrogen rates from Urea at 46%Nitrogen are the typical fertilizer. This can be considered an upper bound as both NPK and Urea are the typical fertilizers used and NPK has lower nitrogen levels.

tropic-warm/semiarid and tropic-warm/sub-humid zones. The classification of tropical stems from the mean monthly temperature[6] being greater than 18ºC for all months. The classification as semi-arid and sub-humid refers to the moisture zones and stems from the average length of growing period (LGP)[7]. The semi-arid zone typically has between 70 and 180 days LGP while the sub humid has between 180- 270 days LGP (Harvest Choice, 2010). Though both are higher than national statistics, the average fertilizer use rates in the semi-arid zone (207.80kg/ha) are lower than the average application rates in the sub humid zone (250.66 kg/ha). This is not surprising given the longer period available for crop growth and the likely difference in adequate moisture; both very important for rice production.

Another dimension across which farming practices and yield response to fertilizer use is likely to vary is across farming systems[8]. According to Dixon et al. (2001) – which is also used by the Food and Agricultural Organization (FAO), Nigeria's farming systems can be categorized into six groups. They are Tree crop, Root crop, Cereal – root crop mixed, Agro-pastoral – millet/sorghum, Pastoral and Coastal artisanal as shown in Figure 3 below.

Figure 1



Source: Dixon et al (2001)

For rice producers in our sample, farmers were categorized into 4 farming systems; Tree crop, Root crop, Cereal – root crop mixed, Agro-pastoral – millet/sorghum.[9] Table 1 reveals

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[6] The mean monthly temperature is adjusted to sea-level using a normal lapse rate of 0.55ºC per every 100 meters of elevation change to get unfragmented geographical areas (Harvest choice, 2010).
[7] The length of the growing period refers to the time which both moisture and temperature are conducive to crop growth
8 According to the FAO, A farming system refers to a group of individual farm systems that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints, and for which similar development strategies and interventions would be appropriate.
9 There were fewer than 10 farmers in the Pastoralist farming system which prevented us from being able to do any comparisons between this group and others. From the map of the local governments in Nigeria where these local governments were found, they relatively close to the agro pastoral farming system and thus these respondents were

higher rates of fertilizer application in the tree crop farming system in the south and south eastern part of Nigeria. Table 1 confirms that conditional fertilizer application rates for rice production are not as low as one may expect, given national and regional statistics and the same applies for the unconditional fertilizer application rates.

Table 1 Mean fertilizer use across farming systems in Nigeria

	Mean fertilizer use per hectare (2010)	% of plots using fertilizer (2010)	Mean fertilizer use per hectare (2012)	% of plots using fertilizer (2012)	Number of observations
Tree crop farming system	478.75	0.57	301.23	0.82	62
Root crop farming system	226.68	0.48	243.83	0.5	239
Cereal-root crop farming system	205.3	0.63	208.21	0.64	386
Agro-pastoral farming system (millet and sorghum)	171.51	0.76	155.02	0.83	43
High Potential States	216.06	0.62	201.44	0.61	319
Other states	236.9	0.55	244.35	0.64	411
No/slight soil nutrient availability problems	192.19	0.52	195.43	0.61	351
Moderate soil nutrient availability problems	273.68	0.67	243.3	0.71	271
Severe soil nutrient availability problems	257.21	0.55	425.96	0.44	67

Source: Authors estimations from the LSMS-ISA data. This average value is conditional on use

The third categorization of rice farmers we use for this study is whether they are located in a high rice potential state. For rice production, Nigeria can be categorized into production zones based on the amount of rice produced in the area. Niger, Kaduna, Kwara, Taraba, Benue and Ebonyi States are considered high rice production zones in the country; producing more than 60% of Nigeria's paddy output(FMARD, 2012). These high potential states are the beneficiaries of several targeted programs geared to improve rice production in Nigeria. Many programs are directly related to inputs including fertilizer and seed while others attempt to stimulate linkages along the rice value chain and provide farmers with better access to output markets. Consequently, they are likely to have different incentive effects for input use. We thus categorize rice producers into 2 groups, those in the states considered high production potential

recategorized into the agro pastoralist system. Running estimations including them in this category versus dropping them from the analysis did not affect the study results and thus this categorization was maintained.

states and other states. Table 1 reveals that average rates of fertilizer application (and the proportion of plots on which fertilizer is applied) are actually slightly lower in this group of high production potential states compared to rice producers in other states. This may be driven by higher quality soils or other management practices[10].

Finally we consider the use of fertilizer across soil nutrient availability. Soil nutrient availability is based on the soil texture, soil organic carbon, soil pH and total exchangeable bases. We categorize rice farmers into 3 groups depending on whether they have any soil nutrient availability constraints. Information on soil quality is at the local government level and was extracted from the Food and Agricultural Organization's, harmonized world soil database (FAO et al. 2012).

Though Table 1 demonstrates significant fertilizer use across soil nutrient availability (in line with other categorizations), it reveals that average fertilizer use rates are actually higher for rice farmers in areas with more soil nutrient availability problems. This appears to reflect the need for nutrients from chemical fertilizers to replenish nutrients exported and lost during cropping to maintain a positive nutrient balance. Generally, we consistently see that fertilizer use rates among rice farmers in Nigeria is much higher than national figures suggest[11].

2.2 The political economy of fertilizer access

This paper uses the political economy of input provision to empirically identify the yield effects of fertilizer in rice production in Nigeria. Several studies have demonstrated how political influence affects allocation of inputs (particularly subsidized inputs) in developing countries (Mason et al., 2013; Sadanandan, 2012; Chapoto, 2012; Chinsinga, 2012; Holden and Lunduka, 2012; Mpesi and Muriaas, 2012; Chinsinga, 2010; Banful, 2011). Several studies have shown how politically well-connected groups receive more inputs (relative to demand) than less connected villages (Holmén, 2005). In other instances, the main beneficiaries in various agriculture related programs have been shown to be the politically connected (Morris et al., 2007; Bazaara and Muhereza, 2003). These are often times those who were not engaged in farming or wealthy farmers who were the least in need of such financial assistance. Along similar lines, Olayide and Idachaba (1987) describe a similar outcome of the agricultural interventions in Nigeria where credit and subsidized inputs were funneled to and captured by "absentee farmers, retired civil servants, and retired soldiers."

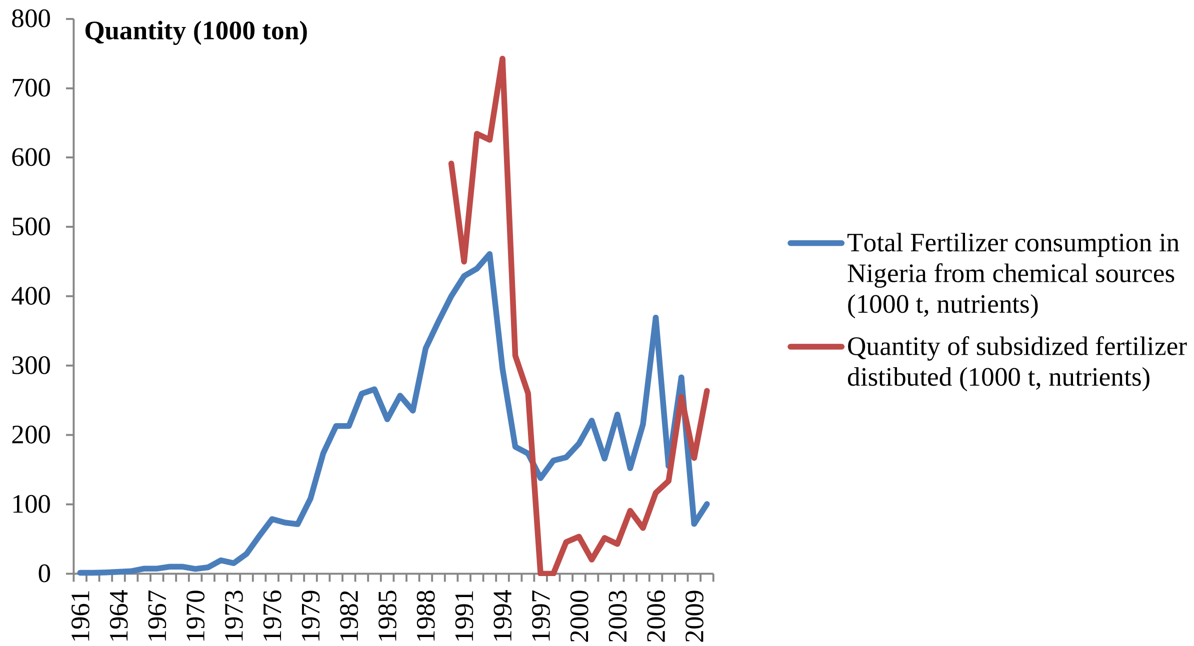
More specific to fertilizer subsidies, descriptive and empirical studies have shown how past election outcomes correlate with subsequent targeting of subsidized fertilizer (Mason et al., 2013; Chapoto, 2012; Chinsinga, 2012; Holden and Lunduka, 2012; Mpesi and Muriaas, 2012; Banful, 2011; Chinsinga, 2010). At the household level, Pan and Christiaensen (2012) demonstrate the politicization and elite capture of input subsidies with evidence from Tanzania. They find that households with elected officials are much more likely to receive an input voucher than other households. In Nigeria, anecdotal evidence suggests that politicians patronize their district of origin by providing fertilizer and this has been demonstrated empirically (Takeshima

[10] Actually, the median fertilizer use values for 2010 were actually higher in the high potential states than the other states but the median values in 2012 were significantly lower. Thus these descriptive statistics are not as clearly suggestive as the mean values indicate.

[11] Though our figures are conditional on use, unconditional use rates still indicate fertilizer application rates much higher than 13kg per hectare.

and Liverpool-Tasie, 2013). We follow Takeshima and Liverpool-Tasie (2013) to exploit this political dimension of access to inputs in Nigeria. While much of the literature till date focusses on subsidized inputs, this study applies the same reasoning within a context where majority of the fertilizer available in the private market is likely to have been subsidized fertilizer (see figure 4) that has been resold in the private market (FFD, 2012). In addition to linking fertilizer access more generally to subsidized fertilizer access, these proposed leakages across space imply that distance from key locations where links to the governor may affect access may also affect the access to commercial fertilizer as well. Consequently, we exploit the variation in proximity to locations where links to a political figure is likely to affect fertilizer access; using the distance of the local government a farmer resides in, to the local government that the governor of the state is from as an excludable instrument for access to fertilizer. We argue that, while the local government where the governor is from is likely to have preferential access to inputs, it should not be correlated with agricultural production except through its effect on input access. We also argue that this instrument is likely to be applicable for fertilizer more generally in Nigeria, if large amounts of subsidized fertilizer leak into the private market and is resold as commercial fertilizer. Figure 5 below reveals that total fertilizer consumption in Nigeria follows very closely (and is often almost identical to) the total amount of fertilizer distributed through the government subsidy program.

Figure 2 Fertilizer consumption relative to the quantity of fertilizer distributed with subsidy in Nigeria



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Source: Consumption is from FAOSTAT, and subsidized quantity is from Federal Department of Fertilizer.

[a]While the FAOSTAT provides the figures comparable over time, most figures are classified as unofficial figures and need to be interpreted with caution.

[b]Quantity of subsidized fertilizer was available only in products. Assuming most of them are NPK 15-15-15 and Urea 45%N, we calculated nutrient equivalent quantity by multiplying 0.45. Subsidized fertilizer from 1998 only includes the quantity distributed by federal government.

[c]The quantity of subsidized fertilizer has sometimes exceeded domestic fertilizer consumption, possibly because substantial amount of subsidized fertilizer has been smuggled into neighboring countries including Niger (Shapiro & Sanders 1998). Anecdotal evidence suggests that this is still likely to occur.

[d]Nagy & Edun (2002) cautions against the reliability of subsidized quantity figures between 1990 and 1994.

3. Conceptual Framework and Empirical methods

Given the multiplicity of market failures likely in rural Nigeria, we model the fertilizer use decision of a farmer as a constrained utility maximization problem as in Singh, Squire and Strauss (1986). As described in Sadoulet and de Janvry (1995), the solution to the constrained maximization problem of an agricultural household yields reduced form specifications of demand for inputs and technologies and supply of outputs. Households typically earn income from the production of multiple crops in addition to any non-farm or off-farm activities. As in Sheahan (2012) we consider agricultural production to be a main source of income and households optimize not only over all activities but also at the plot level.

Sheahan et al. (2013) provides a brief summary of the discussion of functional form selection for crop yield responses. We follow Sheahan et al. (2013) to base our analysis on the quadratic production function which is viewed as a good approximation to the underlying functional form and is widely used in crop yield response analysis (e.g.,Traxler and Byerlee,1993; Kouka et al., 1995).

We can express the effect of input use on output as:

$$Yield_{ijt} = f(\boldsymbol{X_{kijt}}, Z_{kijt}) \qquad (1)$$

Where $Yield_{ijt}$refers to the yield per hectare (in kilograms) of rice on plot i for household j in time t which is a function of several vectors of endogenous and exogenous factors:

$\boldsymbol{X_{kijt}}$, refers to a vector of inputs a farmer applies (including the quantity of fertilizer) per hectare for rice production, $\boldsymbol{Z_{kijt}}$,is a vector of controls that are also likely to affect crop yields such as agronomic conditions or household characteristics

Our primary interest is in estimating the extent to which nitrogen use affects rice productivity. The conceptual model above can be specified as:

$$Yield_{ijt} = \boldsymbol{X1_{kijt}\beta} + \delta Nitrogen_{ijt} + \boldsymbol{Z_{kijt}\gamma} + c_i + \varepsilon_{ijt} \qquad (2)$$

where $Yield_{ijt}$ remains as defined earlier. $Nitrogen_{ijt}$ refers to the quantity of nitrogen applied per hectare for plot i of household j in time t. $\boldsymbol{X1_{ijt}}$ is a vector of input choices. It includes a subset of $\boldsymbol{X_{kijt}}$ such as irrigation, pesticides, herbicides and other equipment. $\boldsymbol{Z_{kijt}}$ is a vector of controls that affects crop production such as soil quality, access to markets, household characteristics including gender of the farmer and household wealth. Finally, ε_{ijt}+ $c_i = u_{ijt}$ is a composite error term comprising time invariant (c_i) and time varying unobserved characteristics $\varepsilon_{ijt}$of our production system while , $\boldsymbol{\delta}$ and $\boldsymbol{\gamma}$ are parameters to be estimated.

A key problem in estimating the effect of fertilizer on yields is the endogeneity of the quantity of nitrogen applied on a rice plot. It is likely that nitrogen application is correlated with other farmer and plot specific characteristics (such as unobserved variation in soil characteristics, managerial skill or ability) that are also likely to drive farmer yields and restricts any causal interpretation to the coefficient on fertilizer use in a yield response model. This correlation between the unobserved individual effect in the error term c_i and the rate of application of nitrogen would cause a bias in ordinary least squares (OLS) estimators (Hausman and Taylor 1981). Consequently, we use a CRE model to address the endogeneity due to unobserved time invariant characteristics. However, there could also be unobserved time varying characteristics that could affect both fertilizer application and yields. To address this potential problem, we use a control function approach (CFA) which is largely an instrumental variables method (Wooldridge, 2010, 2013). We adopt the CFA rather than the typical instrumental variables (IV) or two-stage least squares approaches (2SLS) because our potentially endogenous explanatory variable, nitrogen application is a corner solution (i.e., many households apply zero kilograms of nitrogen) and Wooldridge (2010 and 2013) demonstrate that the CFA is more useful and flexible than IV/2SLS in such cases where non linear models like Tobit are necessary.

For the CRE model, we are able to control for any unobservable household level characteristics that are likely to be correlated with our variable of interest; fertilizer use with information on the agricultural practices of the same households in Nigeria over two years. The CRE estimator allows for correlation between the time invariant unobserved household specific omitted variable and the included explanatory variables. We follow Mundlak(1978) and Chamberlain (1980) who model the distribution of the omitted variable conditional on the means of the strictly exogenous variables instead of treating the omitted variables as a parameter to estimate. One key assumption of this model is that the unobserved household characteristic (c_i) can be modelled as a function of explanatory variables included in the model. Thus following the formulation of Mudlak (1978):

$$c_i = \Psi + \overline{\mathrm{x}}_i \boldsymbol{\delta} + a_i \qquad \text{(i)}$$

$$\mathrm{E}\left(a_i \middle| \mathrm{c}_{i,} x_i\right) = 0 \qquad \text{(ii)}$$

This approach allows c_i to be correlated with the time varying explanatory variables through its average level over time and assumes that upon controlling for c_i in our model the remaining heterogeneity is uncorrelated with all the explanatory variables. Thus, the coefficient on our input use variable of interest (when $\overline{\mathrm{x}}_i$ is included) using pooled OLS is actually the within estimator (Wooldridge, 2010). The CRE approach is operationalized by including the average values (over all the waves of the panel) for each input $X_{k,}$ for each household ($\bar{x}_i$) in the model. The CRE model has a benefit of allowing us to estimate the coefficient on our time invariant variables and can be applied to our unbalanced panel dataset since we are not able to match plots across the two rounds but can identify all plots for the same household across the two years (Wooldridge,2010). Sheahan et al. (2013) apply the CRE to estimate yield effects of Nitrogen for maize production in Kenya, while Mason et al. (2013) and Ricker-Gilbert et al.

(2011) apply these in their estimation of the effect of subsidized fertilizer on private market participation in Zambia and Malawi respectively.

As mentioned above, we apply the CFA to address the effect of time varying unobserved factors that are also likely to bias our estimates of nitrogen application on rice yields. Much like the case for the IV/2SLS approach, the CFA also requires at least one IV that is partially correlated with nitrogen application but that is uncorrelated with the unobserved factors that affect our dependent variable, rice yields. The excludable instrument used in this analysis is the distance from the local government a farmer is from to the local government of origin of the governor[12]. As discussed earlier, as a key politician at the state level with notable power, governors are able to affect input allocations to curry favor or reward loyal electorate. While it is possible that the local government from which this political leader originates could receive a greater allocation of fertilizer or other inputs, there is no reason why being from these local governments should separately affect the productivity of farmers in the local government for any particular crop. Consequently, this variable is considered an appropriate instrument for the CFA.

In equation (2), following Roy (1951) and Cameron and Trivedi (2005; 2009) , $Nitrogen_{ijt} = 0$ is determined by the density $f_1(.)$ such that $Nitrogen_{ijt}$ =0 = $f_1(0)$ and $P(Nitrogen_{ijt})$>0 is determined by $f_2(Nitrogen_{ijt}|Nitrogen_{ijt} > 0)$= $f_2(Nitrogen_{ijt})/1 - f_2(0)$[13] .The associated likelihood function whose log is maximized can be expressed as:

$$L = \prod_i \ |Nitrogen_{ijt} = 0\{f_1(0)\ \} \prod_i \ |Nitrogen_{ijt} \neq 0 \left\{\frac{1-f_1(0)}{1-f_2(0)} f_2\big(Nitrogen_{ijt}\big)\right\} \qquad (3)$$

For the CFA ,the exclusion restriction associated with the first part of (3) is that a subset of controls appears in our final yield response models. Following Wooldridge (2007) and Wooldridge (2008), we estimate a first stage regression of the nitrogen demand for each plot ($Nitrogen_{ijt}$) using a Tobit model. Then the generalized residual is constructed as:

$$\widehat{gr}_{ijt} = -\hat{\tau}\, 1[Nitrogen_{ijt} = 0]\, \lambda\,(-Z_i\hat{\gamma}) + 1[Nitrogen_{ijt} > 0](Nitrogen_{ijt} - Z_i\hat{\gamma}) \qquad (4)$$

Where $\hat{\tau}$ and $\hat{\gamma}$ are the Tobit MLEs and λ is the inverse Mills ratio. Then the generalized residuals are included in the yield production function (Wooldridge 2008). Our instrument; distance from a farmers LGA to that of the governor is used in the tobit models in stage 1 and then it is excluded from our estimation of equation (2). In all second stage estimations, p values are estimated via bootstrapping at 500 repetitions to account for the fact that the generalized residual came from a first stage regression estimation and the errors are clustered at the household level.

[12] Nigeria has 774 local government areas across its 36 states and federal capital territory, Abuja. These local governments are the third tier of government administration below the Federal and State levels of government.
13 This is multiplied by P(Nitrogen ijt)>0 to ensure that the sum of probabilities sum to one.

4. Data

This study uses household panel data from the two waves of the LSMS-ISA data collected by the Nigerian Bureau of Statistics and the World Bank. Input use, yields, prices and farming practices were extracted from the post planting and post-harvest seasons of 2010/2011 and 2012/13. To address challenges associated with outliers, both the input and output variables were winsorized at 99% (or 95% where values at 99% still seemed very large). This involves replacing extreme outlier values beyond the 99th percentile with the value at the 99% percentile rather than dropping the variable. However, where fertilizer use per hectare was still larger than 1 ton after winsorizing, such observations were replaced with a cap value of 700 kilograms per hectare[14]

Due to challenges associated with using the labor data for the first wave of data, household adult equivalency units were used as a proxy for labor[15]. For land size values, all yields and input per hectare values were determined using the imputed land sizes for the self-reported area of each plot in hectares. Where the self-reported area was not available, we supplement with GPS-based measures of plot size, where possible. Due to challenges associated with the units of measures of the quantity of herbicides and pesticides used by farmers, we use a dummy to account for whether a farmer uses a chemical (herbicide or pesticide).

One important question farmers in the LSMS-ISA survey were not asked is whether they are using improved seed or not. This poses a challenge for yield response function estimations as improved varieties are often a complementary input to inorganic fertilizer. Estimations including whether a farmer purchased commercial seed was used and was consistently insignificant alone and interacted with nitrogen application[16].Another important criterion for rice production that was not available in the data set was whether rice production was upland or lowland. We partially control for this with the elevation of the plot measured in meters above sea level as provided by the Shuttle Radar Topography Mission (SRTM) data (Wilson et al., 2007). To capture variation in local production climates, we also include measures of the slope (measured in degrees) and the tropical wetness index derived from modified 90m SRTM (World Bank, 2012).

A dummy variable is used to distinguish farmers who planted rice as a sole crop on the plot versus those engaged in intercropping. While mono-cropping could be a sign of specialization and rice production for commercial purposes, intercropping of rice and sorghum or maize is also used to increase yields and reduce the risk of moisture stress in states like Jigawa, Kano, Bauchi, Katsina, Sokoto, Zamfara and the southern part of Kebbi (Longtau, 2003). This study uses plot area in hectares as the basis for input and output per hectare measures. In our sample, about 70% of rice farmers are monocropping and thus we assume that any inputs used on these plots are applied on the rice.

[14] Estimations were run dropping these observations and this did not change the main findings.
[15] Alternative approaches explored include using the person-days per hectare for the second round as a proxy for the first round; multiplying that value by the amount of hectares allocated to each crop in the first round. Imputed person-day per hectare values using regression methods was a third approach.
[16] This assumes that commercial seed purchases are usually improved seed which might not be true. Since the variable was consistently insignificant, it was not included in the final model.

Table 2 Descriptive statistics for key study variables

Variable	2010		2012	
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**
Yield per hectare (kilograms)	1459.126	2310.168	1518.475	2156.222
Nitrogen per hectare (kilograms)	86.194	104.485	81.205	100.323
Phosphorus per hectare (kilograms)	26.882	27.866	22.316	24.260
Seeding rate (kilograms per hectare)	29.896	111.820	96.146	180.411
Household adult equivalency units	5.365	3.301	5.165	3.340
Mechanization (1/0)	0.131	0.338	0.101	0.302
Irrigation (1/0)	0.146	0.354	0.065	0.247
Chemical use (1/0)	0.620	0.620	0.588	0.493
Organic fertilizer (kg/per hectare)	1.244	1.203		
Male plot manager(1/0)	0.920	0.272	0.930	0.254
Age of plot manager (years)	46.273	14.906	47.038	13.636
distance to central market (kilometers)	69.185	39.731	70.344	40.258
Monocropping rice production	0.538	0.499	0.694	0.462
Assets (Naira)	236,422.40	1,297,553.00	114,711.30	173,026.20
Area planted (hectares)	1.406	3.654	1.230	1.773
Topographic wetness index	15.14263	3.32239	15.089	3.400
Plot elevation (meters)	344.7811	236.3708	339.264	223.362
Slope (percent)	2.653844	2.691736	2.346	2.226
Annual Mean Temperature (0C * 10)	265.2404	12.07813	266.406	10.621
Annual Precipitation (mm)	1157.474	320.3009	1132.070	334.096

Source: Authors calculations using LSMS-ISA data (2010/2011 and 2012/2013)

Table 2 describes our study sample. Average rice yields are about 1460 kg per hectare in 2010 and 1520kg per hectare in 2012. Average fertilizer use appears to have fallen slightly over the period. The typical rice farmer is a middle age male cultivating about a hectare and a half for rice production. While chemical use is prevalent in rice production (over 60% of farmers), the use of irrigation and mechanization (use of tractors or drought animals) is low. Rice yields vary across farming systems and over time. The highest average yields was among farmers in the root crop farming system in 2010 and among farmers in the tree crop farming system in 2012. The tree crop farming system is practiced by farmers in Abia, Cross River, Ebonyi, Enugu and Oyo States, while the root crop system is practiced in Adamawa, Anambra, Benue, parts of Cross river and Ebonyi, Kwara, Nassarawa, Niger and Taraba states. Several of these states are considered high potential rice producing states contributing large shares to the volume of rice produced nationally. Contrary to expectation, average yields in states considered to be high production potential zones is lower than rice producers in other states. This is likely driven by a wide variation in yields (also indicating that even within States, rice productivity variation exists) as median values are higher for high potential states than those not so designated. Similarly rice yields are higher in areas with severe nutrient availability problems compared to those without. Table 1 showed that farmers in these states also tend to use more fertilizer. Though the standard deviations are very large, this may reflect that rice producers in areas with severe nutrient availability problems may be engaging in other agricultural practices to alleviate this soil quality constraint which are yield enhancing such as use of improved varieties or management practices that increase nutrient absorption.

Table 3 Rice yields across diverse agro ecological conditions in Nigeria

Rice production categories	2010		2012		
	Yield (kg/hectare)	Std. Deviation	Yield (kg/hectare)	Std. Deviation	Number of observations
Tree crop farming system	1053.21	2073.13	2944.07	3792.26	62
Root crop farming system	2201.67	2658.42	1884.33	2648.29	239
Cereal-Root crop farming system	1221.00	2182.61	1361.55	2006.51	386
Agro pastoralist farming system	506.62	1066.12	1360.56	1842.79	43
High potential rice state	1417.48	1933.06	1865.95	2712.33	319
Non High potential rice state	1545.70	2623.26	1542.18	2270.31	411
Semi-arid agro ecological zone	1234.94	2144.64	1284.37	2005.82	351
Sub humid agro ecological zone	1710.00	2495.51	2112.45	2841.87	374
No/slight soil nutrient problems	1561.34	2220.93	1677.44	2217.79	351
moderate soil nutrient problems	1832.03	2132.94	2156.28	2645.87	271
severe soil nutrient problems	2256.25	3008.88	2855.94	3255.70	67

Source: Authors estimations from the LSMS-ISA data
**Due to only 1 observation being in the cool sub-humid agro ecological zones, we re-categorized this observation into the warm sub-humid zone thus having only 2 agro ecological zones for rice production.*

5.0 Production function estimates

We present the production function estimates from the CRE-CFA model which combines the CFA and CRE models to address potential endogeneity from two sources: time invariant and time varying unobserved factors. We also estimate the CRE model separately and these results are included in the third and fourth column of Table 6. For the CFA-CRE model, the first stage estimates the factors that determine the demand for nitrogen (our endogenous variable of interest[17]). In addition to the typical variables included in the first stage regression under a CFA, we also include the average over time of all time varying explanatory variables. We estimate Tobit models for nitrogen application to account for the corner solution nature of input use.

[17] We recognize that input use generally is endogenous and this is a common problem of estimating production functions. While the CRE gets at the potential bias due to unobserved time invariant characteristics, we focus on our variable of interest in this study which is Nitrogen application rates.

Table 4 presents the Tobit results. It shows that farmers in local governments in close proximity to the local government of origin of the governor of the state tend to use more fertilizer. The strength of the instrument in the reduced form equation is indicated by the high t-statistic (-2.40) and P-value of 0.01; evidence that the IV is strongly correlated with the endogenous variable. As expected, farmers using complementary inputs including chemicals are more likely to also be using inorganic fertilizer. Similarly, farmers in close proximity to the central market are also likely to have better access to the input and lower transactions cost. Higher fertilizer price has a negative effect on demand and conditional on other factors, farmers in high potential rice production zones tend to use more nitrogen per hectare and plots with levels of tropical wetness were also likely to use more fertilizer. Compared to North Central Nigeria, farmers in South use more fertilizer (see table 6). Not surprisingly, households with more assets (reflecting wealth) tend to use more nitrogen per hectare but the magnitude of this effect is small. Interestingly, nitrogen use among rice farmers in our sample exhibits an inverse relationship. At lower levels of plot sizes, farmers are less likely to use nitrogen but at higher levels, they are significantly more likely to use nitrogen on their rice plots. This may reflect differential credit constraints or different production systems. Contrary to expectation, a higher rice price is also negatively associated with nitrogen use at 10%.

Table 4 Determinants of fertilizer use from first stage of control function- Tobit estimations

	Coefficients	p value
Distance to the local government of origin of the governor	**-26.922****	**0.017**
Seedrate (kg/hectare)	-0.176	0.205
Squared seedrate (kg/hectare)	0.000	0.169
Adult equivalent units	-5.620	0.351
Mechanization (1/0)	5.818	0.853
Irrigation (1/0)	-9.396	0.801
Chemicals(1/0)	44.230***	0.000
Manure use (1/0)	-86.078	0.355
Monocropping (1/0)	31.920	0.166
Sex (1/0)	16.157	0.393
Age (years)	0.353	0.273
Assets (Naira)	0.000**	0.019
Squared asset value (Naira)	-0.000	0.179
Distance to central market (kilometers)	-0.494***	0.002
Area planted (hectares)	-67.151***	0.000
Squared area planted	8.441***	0.000
Topographic wetness index	1.907*	0.074
Plot Elevation (m)	0.023	0.675
Slope (percent)	-0.469	0.802
Annual Mean Temperature (^{0}C * 10)	1.035	0.281

Annual Precipitation (mm)	-0.036	0.516
Price of rice (Naira/kg)	-0.101*	0.073
Price of nitrogen (Naira/kg)	-0.079***	0.000
Moderate soil nutrient quality problems	11.587	0.429
Severe soil nutrient quality problems	-25.649	0.209
Root crop farming system	-0.033	0.999
Cereal-root crop farming system	20.608	0.569
Agro pastoral farming system	-36.365	0.475
North Eastern Nigeria	-16.454	0.477
North Western Nigeria	33.721	0.197
Southern Nigeria	72.117**	0.045
Sub humid agro ecological zone	-40.055	0.137
High potential rice producing zones	37.944***	0.006
2012/1013	6.687	0.541
Constant	-176.283	0.554
Number of observations	639	

Source: estimated by authors *, ** and *** are significant at 10,5and 1% levels respectively. Time averages of all time-varying explanatory variables are included

Table 5 presents the results from the second stage of the CRE-CFA. Nitrogen was interacted with the various farming systems to see how the yield response to nitrogen varies across farming systems. It was also interacted with rice production potential, agro ecological zone and soil nutrient constraints. Due to a high correlation between nitrogen and phosphorus, we focus on nitrogen but interact nitrogen use with phosphorus to account for the effect of nitrogen, in the presence of applied phosphorus. Table 5 presents a high yield response to Nitrogen use in the root crop farming system with its effects tending to decline at higher levels. The only two types of fertilizer we observe farmers in Nigeria using are NPK and Urea. Since the nitrogen component of both types is fixed, the negative coefficient on the interaction term between nitrogen and phosphorus in the root crop farming system likely indicates that Urea has a higher effect on yields than NPK. This makes sense since Nitrogen is often the limiting nutrient constraint in rice production given that other nutrients (like phosphorus (P) and potassium (K) are a bit less mobile. Though for acid soils and soils under constant cultivation, P and K may be lacking (WARDA, …), we find that phosphorus and potassium are consistently insignificant in the yield response models[18]. The evidence on variation in rice yield response to fertilizer nutrients across farming systems in Nigeria appears to be limited once the endogeneity of nutrient use is accounted for. This may be due to the level of aggregation indicating larger variation within rice production. As mentioned earlier, while we distinguish between larger farming systems, there are at least six different types of production systems for rice alone in Nigeria. While production constraints and practices differ among these, this is not captured in this analysis. It is common for different rice farming systems to occur within the same state depending on the location of a rice plot. For example, two major different rice farming systems (with clearly distinguished rice production practices) are upland and lowland farming systems (each of which could be rain fed or irrigated) and we could not directly distinguish this in the data

Compared to farmers planting on soils with severe soil nutrient availability constraints, yield effects of nitrogen are lower in better soils with only moderate nutrient availability constraints. This

[18] Since Nitrogen and phosphorus appear in fixed proportions, it is also challenging to disentangle their separate effects due to multicollinearity challenges

appears to indicate that apart from being important to replenish lost nutrients, soil nutrient quality is likely to necessitate other practices for production which may increase the responsiveness of yields to nitrogen. For example, if soil nutrient quality challenges encourage farmers to deep place their nitrogen rather than broadcast it, this may explain the higher responsiveness to fertilizer application since more of it is available for absorption by the plants roots (than for weeds or than would be lost through the air or ground water). While the marginal product of nitrogen application is statistically significant and substantial for some subgroups of rice farmers, the overall estimated marginal product of nitrogen (estimated using the margins command in 'Stata) of 7.8 kilograms is not significant at 10% or below (Table 6).

Table 5 Rice production function estimates (OLS vs. CFA)

	OLS		**CRE-CFA**	
Rice yield (kilograms per hectare)	Coefficient	p value	Coefficient	p value
Tree crop FS*Nitrogen	3.005	0.814	20.338	0.295
Root crop FS*Nitrogen	33.079***	0.000	40.841***	0.001
Cereal-root crop FS*Nitrogen	0.498	0.952	9.487	0.374
Agro pastoral FS*Nitrogen	-28.019**	0.034	-18.159	0.583
Tree crop FS*Nitrogen Squared	0.013	0.713	-0.001	0.99
Root crop FS*Nitrogen Squared	-0.055**	0.015	-0.051*	0.06
Cereal-root crop FS*Nitrogen Squared	0.007	0.618	0.008	0.664
Agro pastoral FS*Nitrogen Squared	0.321***	0.001	0.392	0.534
Tree crop FS*Nitrogen*Phosphorus	0.178	0.326	0.131	0.953
Root crop FS*Nitrogen*Phosphorus	-0.323***	0.000	-0.355***	0.001
Cereal-root crop FS*Nitrogen*Phosphorus	0.073	0.169	0.05	0.562
Agro pastoral FS*Nitrogen*Phosphorus	-0.304	0.251	-0.555	0.945
No soil nutrient constraints*Nitrogen	3.326	0.316	-6.611	0.279
Moderate soil nutrient constraints*Nitrogen	-4.127*	0.098	-10.714	0.043
Non High potential zone*Nitrogen	3.134	0.240	2.366	0.558
Semiarid Agro ecological zone*Nitrogen	-5.253	0.528	-7.933	0.363
Seedrate (kg/hectare)	1.498	0.586	3.013	0.293
Squared seed rate (kg/hectare)	0.002	0.573	0.001	0.871
Labor (adult equivalency units)	2.588	0.931	100.61	0.368
mechanization (1/0)	5.657	0.982	190.288	0.683
Irrigation (1/0)	37.167	0.908	417.645	0.54
Chemicals(1/0)	-10.493	0.959	174.268	0.408
Organic fertilizer use (1/0)	-296.117	0.372	45.574	0.96
Sex (1/0)	1,190.008***	0.000	943.648***	0.009
Age (years)	6.222	0.259	7.525	0.184
Monocropping (1/0)	13.852	0.938	-270.873	0.514
Assets (Naira)	-0.001*	0.070	-0.002	0.262
Squared asset value (Naira)	0.000	0.125	0	0.498

Distance to central market (kilometers)	5.926*	0.094	3.469	0.292
Plot area (hectares)	-1,160.81***	0.000	-1,195.81***	0.000
Squared plot area (hectares)	142.649***	0.000	125.344***	0.000
Topographic wetness index	17.401	0.372	26.854	0.126
Plot Elevation (m)	-0.071	0.904	0.139	0.823
Slope (percent)	-34.635*	0.090	-34.809	0.168
Annual Mean Temperature (0C * 10)	3.871	0.260	2.625	0.431
Annual Precipitation (mm)	-1.113**	0.020	-1.155**	0.021
Mean Nitrogen	-	-	1.881	0.549
Mean Phosphorus	-	-	8.05	0.529
Mean of area planted	-	-	219.907	0.199
Mean asset values	-	-	0	0.817
Mean seeding rate	-	-	-0.953	0.575
Mean manure	-	-	-326.693	0.715
Mean use of irrigation	-	-	-409.207	0.579
Mean use of mechanization	-	-	-197.599	0.73
Mean monocropping of rice	-	-	233.267	0.628
Mean adult equivalency units	-	-	-112.156	0.338
North Eastern Nigeria	-260.184	0.462	122.2	0.631
North Western Nigeria	-766.984**	0.048	-564.656	0.100
Southern Nigeria	82.092	0.893	16.057	0.981
Tree crop FS* generalized residual (base)	-	-	-1,620.435**	0.035
Root crop FS*generalized residual (base)	-	-	-1,183.098*	0.059
Cereal crop FS*generalized residual (base)	-	-	-921.791	0.104
Agro pastoral FS*generalized residual (base)	-	-	-1,533.13	0.117
No soil nutrient constraints*generalized residual	-	-	1,203.008**	0.037
Moderate soil nutrient constraints*generalized residual	-	-	908.19	0.119
Price of rice (Naira/kg)	2.905***	0.006	2.506**	0.013
Price of nitrogen (Naira/kg)	-0.066	0.837	0.173	0.588
2012/13	122.693	0.488	188.885	0.303
Number of observations	654		639	

*Source: Authors estimations from the LSMS-ISA data. *, ** and *** are significant at 10,5and 1% levels respectively*

Table 6 also shows the importance of addressing the effects of both the time invariant and time varying unobserved factors when estimating nitrogen yield response functions. While the CRE appears to control for some of the endogeneity of nitrogen application, the difference between the CRE and the CRE-CFA likely indicates the presence of some time varying unobserved factors that are correlated with nitrogen application as well as rice yields.

Other important drivers of rice yields appear to be gender of the plot manager and total annual precipitation (rainfall). Male plot managers have higher yields while higher levels of annual precipitation tend to cause lower yields. Though water is very important for rice production, it is said that *submer*gence of the crop and waterlogging in deep water environment and flood prone areas can be a real source of worry to farmers *(Longtau, 2003).* Rice production in Nigeria appears to exhibit the inverse relationship between farm size and physical yield. The plot size variable and its square are negative and positive respectively with both coefficients significant at 1% . This is in line with a lot of other studies feeding into the long debate on this relationship (Chayanov,1966; Sen, 1962; Berry and Cline, 1979; Barrett, 1996). We recognize that plot size is likely measured with error and could also be picking up on other unobserved characteristics of fields of similar size such as different techniques of production.

Compared to North Central Nigeria, rice production in North Western Nigeria is lower. North Central Nigeria consists of major rice producing states like Kogi, Niger, Benue, Kwara, Plateau, Nassarawa and thus this is not too surprising. Higher output prices are associated with higher yields which could be due to unobservable factors that drive investments in rice production as well. The generalized residual is significant at 10% or below in some specifications. The significance of the generalized residual and/or its interactions with other variables both reveals the endogeneity of the nitrogen variable but also corrects for it (Rivers and Vuong, 1988; Smith and Blundel, 1986; Vella, 1993).

Table 6. Marginal physical product of Nitrogen in rice production in Nigeria

	Pooled OLS		**CRE model**		**CFA-CRE**	
Rice yield (kilograms per hectare)	**Marginal effects**	**p value**	**Marginal effects**	**p value**	**Marginal effects**	**p value**
Nitrogen per hectare	7.776***	0.005	6.724**	0.019	7.808	0.173
Phosphorus per hectare	-2.728*	0.094	-3.51	0.255	-3.377	0.873
Seed rate (kg/hectare)	0.472	0.88	0.773	0.822	3.013	0.293
Squared seedrate (Kg/hectare)	0.005	0.36	0.005	0.379	0.001	0.871
Labor (adult equivalency units)	-6.705	0.817	-12.133	0.684	100.610	0.368
Mechanization (1/0)	-96.14	0.701	-75.114	0.856	190.288	0.683
Irrigation (1/0)	124.571	0.751	657.726	0.287	417.645	0.540
Chemicals(1/0)	170.648	0.402	149.114	0.494	174.268	0.408
Organic fertilizer (kg/per hectare)	0	0.768	0.004	0.75	45.574	0.960
Sex (1/0)	939.039**	0.02	922.247**	0.025	943.648***	0.009
Age (years)	-1.133	0.833	-1.961	0.718	7.525	0.184
Distance to central market (kilometers)	3.198	0.315	2.775	0.363	3.469	0.292
Monocropping (1/0)	103.925	0.634	150.41	0.746	-270.873	0.514
Assets (Naira)	0.000	0.698	0.000	0.457	-0.002	0.262
Squared assets (Naira)	0.000	0.836	0.000	0.947	0.000	0.498
Area planted (hectares)	-1,081.134***	0	-1,177.453***	0	-1,195.808***	0.000
Squared area planted (hectares)	127.917***	0	135.206***	0	125.344***	0.000
Topographic wetness index*Total Fertilizer	10.253	0.575	11.481	0.532	26.854	0.126
Plot elevation (meters)	-85.851	0.199	-85.564	0.21	0.139	0.823
Slope (percent)*Total Fertilizer	11.217	0.762	16.924	0.656	-34.809	0.168

Annual Mean Temperature (0C * 10)	7.833**	0.02	6.943*	0.053	2.625	0.431
Annual Precipitation (mm)	-0.800*	0.099	-1.446**	0.013	-1.155**	0.021
2012/2013	-78.831	0.666	-60.605	0.753	188.885	0.303
North Eastern Nigeria	-103.796	0.724	103.916	0.768	0	0.631
North Western Nigeria	-558.114*	0.1	-282.378	0.525	-564.656	0.100
Southern Nigeria	213.936	0.789	526.823	0.52	16.057	0.981
Root crop FS	689.606**	0.021	622.140**	0.044	4.089	0.999
Cereal-root crop FS	-120.057	0.781	-242.254	0.566	-523.823	0.821
Agro pastoral FS	408.068	0.474	320.897	0.617	1,266.570	0.902
Moderate soil nutrient constraints	-310.646**	0.016	-323.538**	0.018	-199.722	0.268
Severe soil nutrient constraints	-292.048**	0.02	-310.489**	0.017	320.963	0.280
Semi arid agro ecological zone	-2.231	0.995	-131.579	0.698	385.863	0.363
High potential rice zone	-88.077	0.461	-60.293	0.613	-115.089	0.558
Time averages included	No		Yes		Yes	
CFA used	No		No		Yes	
Number of observations	650		639		639	

Source: Authors estimations from the LSMS-ISA data
, ** and * are significant at 10,5and 1% levels respectively. P values in parenthesis*

Our results indicate that inorganic fertilizer has a significant and positive overall effect on rice yields among many rice producers in Nigeria. However, this positive effect varies significantly over time and across various dimensions including farming systems type, rice production potential, soil quality, agro ecological and geopolitical dimensions. Table 7 shows how the marginal product of nitrogen application varies across various agro ecological conditions. We find significant effects in the root crop farming systems where the marginal product was 24kg in 2012 and 26kg in 2010. We also find that the marginal product of nitrogen use is significant and large in the sub humid agro ecological zone at about 20kg of rice per unit of nitrogen applied. Similarly, we find a high marginal product of nitrogen (about 20 kg of rice per unit of applied nitrogen) among farmers in the high potential rice production zone.

5.1 Marginal and average productivity across farming systems and agro ecological zones

This section explores this variation by focusing on the marginal product estimates from the CFA-CRE to the farming system, soil quality, agro ecological and rice potential zones. These marginal products are the Average partial effects from the CFA-CRE model for various subsets of rice farmers in our dataset. This aggregation reveals marginal physical products (MPPs) for nitrogen that are statistically significant (and positive) for the root crop farming systems. Estimates of the Average physical product (APP) confirm this large and positive effect. The marginal and average products for the root crop system are similar between 2010 and 2012; though higher in 2010. The marginal products for nitrogen in rice production for other farming systems are not significantly different from zero. However, the marginal and average products are consistently negative for the agro pastoral farming system and very small or negative for rice producers in the cereal-root crop farming system.

Table 7 also reveals that the marginal product of nitrogen is high and statistically significant in the sub humid agro ecological zone compared to the semi-arid agro ecological zone. Similarly, the marginal product of nitrogen for rice production is higher for farmers in the high potential production zone where application rates are lower. This is in line with the notion that higher application rates would be associated with lower response rates per unit of applied fertilizer and with Sheahan et al. (2013) who find higher marginal and average products of Nitrogen for maize production in the lowland areas of Kenya where fertilizer application rates were lower. They interpret this to potentially be a reflection of the fact that fields with a long history of fertilizer application may no longer experience the same gains as those more recently brought into fertilizer use, if complementary inputs were not part of the management practice. Finally, table 7 reveals that the marginal product for farmers operating on soils with severe soil nutrient constraints ranges was 17.3 and 15.39 for 2010 and 2012 respectively compared to -1.9 and -2.34 (not statistically significant at 10% or below) for the same periods for farmers with no soil nutrient constraints. Consequently, the marginal products for soil quality are consistent with the idea that the returns to fertilizer use are actually higher when soil nutrient availability constraints are more. This may be explained by soil nutrient quality challenges encouraging farmers to adopt practices that cause nitrogen efficiency to be higher as explained earlier. The empirical results also indicate that the marginal product of nitrogen for rice production is consistently significant and high in North Central Nigeria in both periods and for Southern Nigeria in 2010 compared to the North East and North West (see table 8).

Table 7 Marginal product of nitrogen for rice production across Nigeria (CFA-CRE Estimates)

	Tree crop FS	Root crop FS	Cereal-root crop FS	Agro pastoral FS	Semi-arid AEZ	Sub-humid AEZ	HPZ	NHPZ	No Cons	Mod cons	Severe cons
MP (2010)	14.88	26.63***	-0.37	-12.91	-3.09	18.22***	15.32***	3.44	-1.09	3.24	17.34+
MP (2012)	13.46	24.64***	-1.05	-12.60	-3.23	17.75***	14.52**	1.70	-2.34	2.92	15.39***
AP(2010)	13.52	22.23	-1.09	-23.21	-4.39	15.26	9.42	0.41	2.00	5.01	14.12
AP(2012)	13.02	21.81	-1.98	-21.85	-4.80	16.02	10.89	-0.83	0.27	6.08	17.17

*Source: Authors estimations from the LSMS-ISA data. *, ** and *** are significant at 10,5and 1 percent respectively. Nocons=no/slight soil nutrient availability constraints, Modcons=moderate soil nutrient availability constraints and severecons=severe soil nutrient availability constraints*
+ is significant at 15% or less

Table 8 Marginal product of nitrogen for rice production across Nigeria's geopolitical zones (CRE- CFA)

Geopolitical zones	Marginal product
North central (2010)	16.99**
North central (2012)	21.52***
North East (2010)	5.420
North East (2012)	3.370
North West (2010)	-3.850
North West (2012)	-4.610
South (2010)	20.21**
South (2012)	12.27+

Source: Authors estimations from the LSMS-ISA data

, ** and * indicate values are significant at 10,5and 1% levels respectively*

Other studies in Nigeria have found a wide range of marginal products for fertilizer use in rice production. This large variation (largely across space) in marginal products for rice in Nigeria reveals the need to distinguish fertilizer profitability and use across various dimensions. In a study in Ebonyi State, Offodile et al. (2010) found marginal products of fertilizer ranging between 31 and 33 among female and male rice producers respectively. Ebonyi State in our study falls under the root crop farming system where marginal products were between 24 and 26. Along similar lines, Adedeji et al (2014) in a study of rice farmers in Kwara State find a marginal physical product of fertilizer of 27.6. Kwara State is among the high potential zones for rice production where our marginal products are between 14 and 15. Akighir and Shabu (2011) estimate the MPP for fertilizer in Kwande Local Government Area of Benue State, Nigeria to be 10.7. They also find that MPPs were higher than the APPs suggesting an underutilization of fertilizer and other productive resources. Benue state falls under both the root crop farming system and the high potential zones where we get the highest marginal products. Contrasting results can also be found across Nigeria. Oniah et al. (2008) in a study on swamp rice production in Cross Rivers State found marginal products of fertilizer to be much lower; about 3.7kg. Cross Rivers State falls into the tree crop farming system where marginal products for Nitrogen were low and largely insignificant. Omonona et al. (2012) actually find negative marginal product for fertilizer among Ofada rice producers in Ogun State (South West Nigeria). Though we do not have Ogun State in our sample of rice farmers, Ogun State falls into the root crop farming system where this study and Offodile et al. (2010) find higher marginal products. Given that Omonona et al (2012) focus on Ofada rice producers; this may reflect variation within the state in practices and nutrient response across different types of rice production.

Generally, our estimates are slightly lower than those of the other studies. This may reflect the effect of accounting for the endogeneity of fertilizer use. It should also be noted that our results are not directly comparable to these other studies as they focus on total fertilizer, while our study specifically looks at the effect of Nitrogen. However, the general results of our study are largely consistent with others in Nigeria and confirm the benefit of using a nationally representative dataset to be able to tease out the heterogeneity of the marginal product of nitrogen within one consistent analytical approach.

5.2 Profitability of fertilizer use

The profitability of fertilizer is likely a key factor in determining fertilizer use. Yanggen et al. (1998) discuss the importance of the technical response to fertilizer use[19], the relationship between output price and fertilizer price and the Value-Cost Ratio (VCR), which is simply the ratio of the technical response to fertilizer use and the nutrient/output price ratio. A VCR of greater than 2 is generally considered necessary in a developing economy to provide to provide incentives for fertilizer use with higher ratio's (like 3 or 4) needed in really risky environments (Morris et al.,2007; Kherallah et al.,2002).

To estimate the profitability of fertilizer use for rice production, we use the marginal and average products of nitrogen for each agro ecological zone, farming system and rice potential zone. These figures (table 7 and table 8) indicate that fertilizer use may be profitable; depending on the cost of fertilizer and the market price for rice. We also estimate the average product of Nitrogen in rice production from our data. We calculate the average product as the change in output due to the use of fertilizer. This captures the gain in yield per unit of nitrogen compared to not applying any Nitrogen.

Consequently, average products were calculated at the plot level for each year using the coefficients from the CRE-CFA model and then averaged to the farming system, soil nutrient challenge group, agro ecological and high potential zones (Sheahan et al., 2013). We find that on average, the average product values are lower than the marginal products. This indicates that all being equal, an additional kilogram of Nitrogen contributes more to output than the average and thus farmers could benefit by using more nitrogen. We note that the magnitude of the standard deviation on our calculated average products varies across different categorizations. This likely indicates the importance of other local household or field characteristics important for nutrient response that should be borne in mind.

We define the profitability of nitrogen as occurring where the marginal value product of fertilizer exceeded its market price (Marenya and Barrett, 2009). This is equivalent to saying where the MVCR or AVCR is greater than 1. With an AVCR greater than one, farmers can increase their income with fertilizer use. However, with a MVCR of greater than one, a farmer can increase his income by increasing his rate of fertilizer application. As in Sheahan et al. (2013) we distinguish between the level of profitability for a risk neutral farmer and that for a risk averse farmer. Also, following Anderson et al. (1977), we consider that with a risk premium of 1 (e.g., Xu et al., 2009; Sauer and Tchale, 2009; Bationo et al., 1992), a MVCR of 2 is what a risk averse farmer would need to have to find nitrogen application profitable. We consider MVCR and AVCR values greater than 2 to be an adequate indicator of profitability of nitrogen application for rice production.

5.3 Nitrogen and Rice prices

The majority of fertilizer used for rice production is either NPK or Urea. Consequently, the price used for nitrogen is the average price paid by households for the nitrogen portion of Urea and NPK, averaged at the local enumeration area of the LSMS-ISA data. To account for the importance of transportation costs in input use (as shown in Winter-Nelson and Temu, 2005; Morris et al., 2007; de Janvry et al., 1991; Key et al.,2000; Bellemare and Barrett, 2006) we also include the average transportation cost for procurement of fertilizer by local government. Fertilizer prices from the data were calculated as the value paid for fertilizer divided by the quantity purchased. In communities where the resulting price of fertilizer was less than N50[20] per kilogram of fertilizer or missing, the local government average was used and where that was not available, a state level average fertilizer price was used. To address persistently extreme values (beyond N1000/kg), fertilizer prices were winsorized at 95%. Extreme values after winsorizing (greater than N250/kg) were also replaced with the local government

[19] This is measured by the units of output (O) produced from one unit of nutrient (N) input (the O/N ratio

[20] The price for fertilizer in 2010 was between N4500 (for a 50kg bag) and N6000 which amounts to about N90/kg

or state average. For communities in 2012, where fertilizer price data was not available but there was fertilizer price in 2010, the 2010 price is multiplied by the average rate of inflation over the planting season in rural areas in 2012.

Table 9a Share of transactions cost in total fertilizer prices in Nigeria

	2010	2012
NPK Price	178.73	225.00
NPK TC	771.53	877.61
Share of total fertilizer price due to transactions cost	0.77	0.74
Urea Price	182.87	182.83
Urea TC	990.35	835.44
Share of total fertilizer price due to transactions cost	0.82	0.78

Source: Authors estimations from the LSMS-ISA data, TC=total acquisition cost. Prices are adjusted to 2012 prices using the cpi from the Nigerian National Bureau of Statistics

Table 9a reflects that transactions cost (proxied) by transportation cost to acquire fertilizer) are very high in Nigeria. This echoes the findings of other studies that transportation costs account for 20-25% of the urban retail prices at regional hub cities in Nigeria (Liverpool-Tasie and Takeshima, 2013). This effect is likely exacerbated at rural markets and (even further in remote villages) to capture the costs of getting the fertilizer to more remote areas with poorer road networks. As table 9a shows, transportation costs are between about 70 and 80 percent of the average actual price paid for fertilizer. While it is true that a farmer bears this cost irrespective of the quantity of fertilizer being purchased, we recognize that adding the total cost of procurement to the per unit price may overestimate the effect, given that farmers are likely to procure fertilizer in larger amounts as well as engage in other activities during such trip to procure fertilizer. However, these results indicate that transactions costs are likely to be an important factor in determining the profitability of fertilizer use for rice and crop production more generally.

The output price used for this analysis was the average of the post planting and post –harvest community price per kilogram of rice. While it is likely that farmers decisions to use fertilizer during the planting season are driven by expected prices of rice rather than the actual price at post planting, the unavailability of good price information at the community or local government level precluded our ability to explore options to generate such expected prices as described in Muyanga(2013) and used by Sheahan et al.(2013) in their estimation of the effect of Nitrogen on maize yields in Kenya. Again, where prices were unavailable or extremely small (less than N10 per kg), they were replaced with local government averages or state level averages. Similarly, where prices for rice were more than N300 per kilogram, they were replaced with N300 per kilogram; an amount to capture the higher cited rice prices between (2010-2013) due to the various policies.

We calculate the ratio of fertilizer nutrient price to rice price (PN/PO) where PN and PO refer to the price of Nitrogen and the output price (rice) respectively. This ratio indicates how much output is needed to purchase a kilogram of fertilizer or Nitrogen. The rule of thumb is the lower the price ratio, the more profitable the use of fertilizer. Generally, these values indicate that Nitrogen cost is high relative to output prices. This static comparison is difficult due to the difference in products (fertilizer and rice) but the movement over time can be informative. Though only spanning two years, it appears that the price ratios have increased between 2010 and 2012. Usually, input output price ratios are lower for crops such as rice which tend to fetch a higher market price than commodities such as maize (see table 9b). Note that these estimates are a lower bound as we do not incorporate the full acquisition cost of fertilizer into the calculation of this ratio. When we incorporate acquisition costs, the price ratios increase significantly; more than doubling, given the high cost of transportation.

Table 9b Price ratios (Price Nitrogen/Price rice) Naira/kilograms

	Tree crop FS	Root crop FS	Cereal-root crop FS	Agro pastoral FS	Semi-arid AEZ	Sub-humid AEZ	HPZ	NHPZ	No Cons	Mod cons	Severe cons
PN/PO (2010)	7.12	3.505	1.883	2.187	1.76	3.729	3.45	2.35	1.88	4.43	2.755
PN/PO (2012)	11.2	4.517	2.499	3.464	2.225	5.977	4.199	3.9	2.86	8.47	4.107

Source: Authors estimations from the LSMS-ISA data. Nocons=no/slight soil nutrient availability constraints, Modcons=moderate soil nutrient availability constraints and severecons=severe soil nutrient availability constraints

Next we compute the marginal value cost ratios and the average value cost ratio’s using the marginal and average products from our production function estimates with the fertilizer and rice prices. Both estimates indicate that fertilizer use for rice production is only profitable for some rice farmers in Nigeria and profitability varies significantly over time. For farmers in the root crop farming system, MVCR’s are very high ranging between 7 and 12. This indicates that nitrogen application on rice production is profitable even for a risk averse farmer. This is also the case for the tree crop farming system, for high potential rice producing states, those in the sub humid agro ecological zones and farmers with severe soil nutrient quality issues. The MVCR for these 4 categories lies between 2.6 and 12. The AVCR’s for these groups are generally lower but still higher than 2. While the AVCRs for the root crop farming system, sub humid agro ecological zone and among severe soil nutrient challenges range between 5 and 10, they are lower between 2 and 4 for the tree crop farming system and is actually higher than 2 for those in the moderate soil nutrient quality challenges group. Note that AVCRs give a sense of overall profitability of nitrogen application, while the MVCRs relate to the profitability of a given level of nitrogen and provide insight about the possibility of profitable expansion. Even when current application rates are profitable, an AVCR less than 2 is not likely to be considered profitable for the average rural farmer who is likely to be more risk averse.

In line with the production function estimates, fertilizer use is not profitable in the agro pastoralist farming system and in the semi-arid agro ecological zone. For farmers in the Non high potential states and among those with moderate soil nutrient constraints, nitrogen application is not consistently profitable at current application rates (MVCRs were 2.64 and 1.02 in 2010 and 2012 respectively), AVCR is always less than 1.

Table 10 Marginal and average value cost ratio of Nitrogen for rice production across Nigeria

	Tree crop FS	Root crop FS	Cereal-root crop FS	Agro pastoral FS	Semi-arid AEZ	Sub-humid AEZ	HPZ	NHPZ	No Cons	Mod cons	Severe cons
MVCR 2010	5.36	12.72	-	-	-	8.93	6.99	2.64	-	1.57	11.12
MVCR 2012	2.61	8.69	-	-	-	5.67	5.36	1.02	-	1.02	5.59
AVCR 2010	4.869	10.618	-0.816	-18.519		7.483	4.301	0.314	1.48	2.43	9.06
AVCR 2012	2.52	7.7	-1.24	-14.12	-3.18	5.126	4.021	-0.499	0.175	2.13	6.24

Source: Authors estimations from the LSMS-ISA data. Nocons=no/slight soil nutrient availability constraints, Modcons=moderate soil nutrient availability constraints and severecons=severe soil nutrient availability constraints

5.4 Fertilizer profitability and Observed use rates

To compare fertilizer use rates with the expected profit maximizing levels, we follow Sheahan et al. (2013) to use the estimates from the production function to derive the amount of nitrogen that should be applied for the marginal value cost ratio to be equal to 1. These calculated optimal rates (where MVCR=1) found in Table 10 indicate that observed use rates are often lower than the expected profit maximizing application rates. However, in two farming systems and among farmers in the semi-arid agro/ecological zone, mean application rates are actually higher than the expected profit maximizing rates[21].

The highest MVCR and AVCRs are found among the root crop farming system, the sub humid AEZ, rice farmers in the High potential zones and rice farmers with severe soil nutrient constraints. Interestingly, observed mean nitrogen application rates tend to be lower than the mean application rates of other farmers(in the other comparison group) and this hasn't changed much between 2010 and 2012. For example, the mean nitrogen application rates among farmers in the root crop farming is less than 40kg/ha while the mean application rates for farmers in the other farming systems ranges between about 40 and 90kg. Similarly, observed nitrogen application rates among farmers in the high potential zone states (about 43kg/ha) and those in the sub humid AEZ (about 41kg/ha) have mean use rates lower than the farmers in the non high potential zones (about 55kg/ha) and in the semi-arid AEZ (about 56kg/ha). As expected, with higher marginal physical products of nitrogen application, these groups of farmers with higher MVCRs and AVCRs have significantly higher expected profit maximizing rates. Consequently, these results indicate that for these farmers, though fertilizer use may not be as low as expected, there is room for expansion of nitrogen application. For the root crop farming system and farmers in the sub humid AEZ, there is room for both expanding the proportion of farmers applying nitrogen for rice

[21] It should be noted that this study captures average relative profitability of nitrogen application and variation across households and plots. It is an important factor that should be considered when thinking about the appropriate fertilizer application rates.

production and the application rates. Current application rates are more than 50% less than the expected profit maximizing rate.

The next set of farmer categorizations with borderline MVCRs and AVCRs are those farmers in the tree crop farming system, non high potential zones and farmers in areas with moderate soil nutrient availability problems (these groups are only profitable when market prices for nitrogen and not full acquisition costs are considered). Here we also see average use rates generally lower than expected profit maximizing levels. For farmers in the non high potential rice producing states, the mean use rates in 2010 are almost identical to economically optimal levels and the mean use rate in 2012 is actually higher than the expected profit maximizing application level. Observed mean application rates are also higher for subgroups of farmers for which we found low or negative marginal physical products of fertilizer. Farmers in the semi-arid AEZ and the agro pastoralist and cereal-root crop farming system had negative MPPs and for all these farmers we see nitrogen application rates in excess of what is considered to be appropriate levels to maximize expected profit. We also see that in these groups, nitrogen is applied on between 63% and 83% of all rice plots. These higher than expected profit maximizing levels may be partially explained by increasing soil acidity and micro-nutrient depletion where inorganic fertilizer has been used for a long time as explained by Sheahan et al. (2013). Majority of farmers in these subgroups are in the Northern Part of Nigeria; generally considered to be characterized with low soil fertility and having a long history of fertilizer use. These results may also be reflecting the effect of fertilizer policy in the North where subsidy levels have historically been higher (Banful et al., 2010). They also indicate that expanding nitrogen application for these subgroups of farmers is not profitable given the MPP of nitrogen for rice production and the relative prices of nitrogen and rice.

While considering expected profit maximizing application rates when MVCR=2 (to account for the risk aversion of smallholder farmers) reduces the expected profit maximizing levels, the observed pattern is similar to the case for MVCR=1 with potential room for expansion in fertilizer use among farmers in the root crop farming system, the sub humid agro ecological zone, farmers in the high potential rice zones and those with severe soil nutrient constraints. Similarly, considering the full acquisition cost of fertilizer yields similar observed patterns between expected profit maximizing rates of nitrogen application and observed use levels. Government recommended rates of fertilizer application in Nigeria often depend on whether it is upland or lowland rice production and also on the soil quality. Generally, nitrogen application rates of between 60 and 80kg per hectare are recommended (WARDA….). For soils with poor soil quality, higher levels (between 100 and 120) are recommended while for soils with high quality, lower levels (about 40kg/ha) are recommended. While most mean application rates are lower than government recommendations, our ability to allocate the relevant government recommendation is limited. However, for the group of farmers with slight to no soil nutrient constraints,(where we are able to more confidently apply the government recommended rate of about 40kg/ha) we see mean application rates of 40.5kg/ha almost exactly in line with the government recommended rates and just slightly lower than application rates associated with expected profit maximization rate of 50Kg/ha.

The mean expected profit maximizing nitrogen application rates for high potential areas in Nigeria (using our production function estimates) tends to range between 150kg/ha and 220kg/ha. Nneke and Ndon (2003) find optimal nitrogen application rates for swamp rice in South Eastern Nigeria to be about 150kg/hectare. Ezuiet al. (2010) also cite between 51–133 kg as the recommended application rate of Nitrogen for an expected take up of the recommended amount of Nitrogen for upland rice production in Nigeria. Depending on the method of application, required amounts may be higher due to the high rate of loss of Nitrogen into the air or water (FAO,2000). Studies in other parts of the world reflect this high nitrogen application for rice production. Xia and Yan (2011) find economically optimal rates of Nitrogen for rice production in China to be 187 kg per hectare while Mahajanaet al. (2011) find 150kg applied in 4 splits is most optimal for rice production. Wanget al. (2004) calculate that for the two major paddy soils (Hydromorphic paddy soil and Gleyed paddy soil) of the region of China they were studying, the optimal N application rate was 225-270 kg N per hectare for rice.

Table 11 Nitrogen profitability and observed use levels in Nigeria

	Estimated Optimal N (kg/ha) MVCR=1	Actual N (kg/ha)	% of plots using fertilizer (2010)	Estimated Optimal N (kg/ha)	Actual N	% of plots using fertilizer (2012)
Tree crop farming system	108.47	86.36	0.57	90.01	83.56	0.82
Root crop farming system	210.40	36.28	0.48	191.84	47.14	0.50
Cereal-Root crop farming system	35.88	50.99	0.63	38.74	46.29	0.64
Agro pastoralist farming system	26.01	40.65	0.76	25.57	28.90	0.83
High potential rice state	151.41	43.00	0.62	152.60	42.79	0.61
Non High potential rice state	55.14	51.75	0.55	38.70	54.64	0.64
Semi-arid agro ecological zone	21.32	55.93	0.72	28.94	48.33	0.72
Sub-humid agro ecological zone	156.71	41.23	0.50	146.01	50.40	0.55
No/slight soil nutrient problems	50.00	40.45	0.52	38.47	38.54	0.61
Moderate soil nutrient problems	126.40	66.19	0.67	124.78	59.95	0.71
Severe soil nutrient problems	189.75	34.77	0.55	188.25	87.93	0.44

Source: Authors estimations from the LSMS-ISA data

5.5 Accounting for full cost of procuring fertilizer

To account for the fact that the fertilizer price used in the calculation of the profitability of fertilizer use did not fully incorporate the cost of acquiring the product, we recalculate our MVCR and AVCR values using the full acquisition cost of fertilizer. As expected, the input output price ratio increases significantly across all farming systems; by more than 100% in most cases. Consequently, the MVCR and AVCR also fall significantly. The profitability of fertilizer use consistently remains for only the root crop farming system and farmers with severe soil nutrient constraints. For farmers in the sub humid agro ecological zone and high potential rice zones, the AVCR are mostly now between 1 and 2 (though the MVCR is about 4 in 2010 and 3 in 2012 in these systems respectively), thus likely not to be considered to be profitable for a risk averse farmer. As a result, Table 12 demonstrates a longstanding challenge often cited with technology adoption in rural settings; transactions cost (Winter-Nelson and Temu, 2005; Morris et al., 2007; de Janvry et al., 1991; Key et al.,2000; Bellemare and Barrett, 2006). These study results indicate the importance of strengthening links between farmers and input suppliers as well as infrastructural development fertilizer use in Nigeria. While technical yield response to fertilizer for rice production is high in many cases, the acquisition cost for fertilizer is so high that it significantly reduces the profitability of fertilizer use for many rice farmers.

Table 12 Marginal and average value cost ratio of Nitrogen for rice production across Nigeria using full cost of acquiring fertilizer

	Tree crop FS	Root crop FS	Cereal-root crop FS	Agro pastoral FS	Semi-arid AEZ	Sub-humid AEZ	HPZ	NHPZ	No Cons	Mod cons	Severe cons
MVCR 2010	2.06	5.98	-	-	-	4.13	1.31	0.47	-0.40	0.81	5.19
MVCR 2012	0.98	3.33	-	-	-	2.21	3.44	1.32	-0.70	0.48	2.17
AVCR 2010	1.87	4.99	-0.42	-8.75	-1.84	3.46	2.11	0.16	0.74	1.25	4.22
AVCR 2012	0.946	2.95	-0.58	-8.41	-1.55	1.98	1.83	-0.227	0.08	1	2.42

Source: Authors estimations from the LSMS-ISA data. Nocons=no/slight soil nutrient availability constraints, Modcons=moderate soil nutrient availability constraints and severecons=severe soil nutrient availability constraints

6. Conclusions:

This paper looked at the effect of nitrogen application on rice production across farming systems, agro ecological zones, soil nutrient quality and rice potential in Nigeria. Using the LSMS-ISA panel data for 2010/2011 and 2012/2013, we explore the effects of nitrogen application on rice yields. We use both a Control Function Approach and a Correlated Random Effects model to address the endogeneity of nitrogen application when estimating a rice production function.

We find evidence that the proximity to the local government of origin of the state governor increases access to fertilizer and that the marginal physical product of nitrogen application significantly varies across time and space. This variation in significance of applied nitrogen across various agro ecological conditions is consistent across empirical approaches used and in certain farming systems, the marginal physical product of nitrogen is actually negative. The yield response of nitrogen for rice production in the root crop farming system (also in the sub-humid agro ecological zone and among high potential rice producing states) and the value of this additional product yield marginal and average value cost ratio’s, higher than the breakeven point for risk neutral and risk averse farmers (1 and 2 respectively). Incorporating the cost of transportation into the price of fertilizer significantly reduces the profitability of fertilizer use and calls into question the profitability of its use in many cases.

Expected profit maximizing nitrogen application rates were estimated and compared to actual use rates observed. For the most part, farmers with high potential for rice production (as revealed by their

MPPs and MVCRs), tend to be using nitrogen amounts significantly below the levels associated with expected profit maximizations. However, among several groups of farmers with low or negative MPP of nitrogen, observed fertilizer use rates are actually beyond optimal levels. For a few groups of farmers (like those with slight/no soil nutrient problems) we actually find mean nitrogen application rates that are very close to the expected profit maximizing levels and almost identical to government recommended rates.

Generally, this study confirms that fertilizer use which is clearly evident in rice production in Nigeria (about 60% of the study sample using some fertilizer) can be profitable[22]. While there is likely room for expanding fertilizer use among some rice farmers, there are some rice farmers (particularly in the farming systems in the North and semi-arid AEZ) whose mean nitrogen application is already beyond levels considered economically optimal. This study concludes that fertilizer use in rice production in Nigeria is not as low as conventional belief suggests. Furthermore, while policies to reduce the transactions costs associated with procuring fertilizer across rural Nigeria could go a long way to increase the profitability of fertilizer use, a higher rate of fertilizer use does not seem enough for some farmers. For some plots, likely where fertilizer application has persisted over long periods, the benefit of application may no longer be sufficient, indicating a high need for complementary inputs (such as good quality seed and other more efficient methods of fertilizer use or crop management practices). Other factors that could be important are the timely access to fertilizer and credit constraints. Further empirical studies on these issues will be useful to shed more light on the extent to which they contribute to the observed fertilizer use rates across the country.

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[22] A full scale profitability would be necessary to make this claim as fertilizer use has other dimensions such as increased labor demand for application and consequent weeding and this has not been taken into account yet.

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