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Is fertilizer use really suboptimal in sub-Saharan Africa? The case of rice in Nigeria

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This article revisits a conventional wisdom that inorganic fertilizer use across sub Saharan Africa is too low. This assumes that it is profitable to use rates higher than observed. The paper exploits the political economy of fertilizer access in Nigeria to obtain consistent estimates of the effects of applied nitrogen on rice production. We find the yield response to applied nitrogen to be marginal in the main rice growing farming system. Farmer behavior is not inconsistent with profitability which is limited by a low yield response to fertilizer, high transportation costs and low selling prices for rice in rural areas.

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Key words: Fertilizer profitability, rice, marginal physical product, political economy, Nigeria, Africa

JEL codes: Q12, Q18, D24

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1.0 Introduction

Despite a widely accepted view that increased use of modern inputs like inorganic fertilizer is necessary for sustained productivity growth, the use of inorganic fertilizer is considered low in Sub Saharan Africa (Sheahan and Barrett, 2014; Sommer et al., 2013; Monpellier, 2013; Jayne and Shahid, 2013). The reasons offered to explain low adoption rates for modern inputs are diverse. They include lack of familiarity by farmers with the technology (Birner et al., 2009; Feder et al. 1985; Minten et al, 2013), limited or untimely availability of the input (Carlsson, et al., 2005; World Bank, 2006), farmer motivation and procrastination issues (Duflo et al., 2008; 2011), riskiness and credit constraints (Feder et al. 1985, Croppenstedt, Demeke and Meschi, 2003).

The idea that fertilizer use in SSA is "too low" is based on the assumption that it is profitable to use rates higher than is currently observed. However, rigorous empirical evidence to support this notion is limited and few studies have actually explored the profitability of fertilizer use (Liverpool-Tasie et al., 2015a). Furthermore, most studies on fertilizer use do not address the endogeneity and corner solution nature of fertilizer use in crop production[1] (Offodile, 2010; Omonona et al., 2012; Akighir and Shabu, 2011; Adedeji et al., 2014). This paper follows previous work by Liverpool-Tasie et al. (2015a) to combine information on fertilizer agronomics (rice yield response) with fertilizer economics (the output/input price ratios as well as transportation costs) to explore the profitability of nitrogen application for rice production in Nigeria. Using panel data and instrumental variable (IV) techniques, we address both the endogeneity and corner solution nature of the nitrogen application decision. We exploit the political economy of fertilizer access in SSA to empirically estimate consistent estimates of the effects of applied nitrogen on rice yields. We use these estimates and observed input and output prices to explore the profitability of nitrogen application. Next, we estimate the expected profit maximizing quantities of applied nitrogen for rice production (adjusted to account for the riskiness of fertilizer use for smallholder farmers) and compare these to the actual rates used by rice farmers.

This article contributes to the literature on fertilizer use in several ways. First, this paper contributes to the limited empirical evidence exploring the popular notion that fertilizer use is *too*

[1] Liverpool-Tasie et al (2015a) is the only paper found in Nigeria (for maize production) while Sheahan et al (2013) and Xu et al (2009) are examples for maize in Kenya and Zambia respectively. However, neither of these studies address the corner solution nature of fertilizer application nor the potential effect of time varying unobservable factors.

low in SSA, even though it is profitable. Second, this study accounts for both time invariant and time varying unobserved characteristics likely to affect fertilizer application and rice yields. Thus we extend the approach of Sheahan et al. (2013) and Liverpool-Tasie et al. (2015a) to address not only endogeneity of fertilizer use due to time invariant unobserved characteristics (which they consider) but also to address the potential effect of time varying unobserved factors. Third, we also extend their work by accounting for the corner solution nature of inorganic fertilizer use in crop production[2]. Fourthly, this paper addresses the profitability of fertilizer use for a different crop; rice, as most of the current literature has focused on maize (Xu et al. 2009; Sheahan et al., 2013; Snapp et al, 2014; Liverpool-Tasie et al., 2015a).

The rest of the article is organized as follows. Section 2 describes fertilizer use for rice production in Nigeria. We then present our conceptual framework and empirical methods in section 3. Section 4 presents the data used for the study. Section 5 presents and discusses the study results This includes the production function estimates, marginal (and average) products of applied nitrogen and the analysis of the profitability of nitrogen application for rice in Nigeria's main rice producing farming system. Section 6 concludes.

2.0 Fertilizer use for rice production in Nigeria

Nigeria is a major importer of rice. This is driven by population growth, urbanization and a preference for rice, which have seen rice demand grow faster than domestic supply. Heavily dependent on imports, recent spikes in global cereal prices have led to expanded efforts to promote national self-sufficiency in rice. Key among these efforts is an attempt to stimulate domestic rice production through the dissemination and adoption of modern technologies like seeds and fertilizer. This strategy is also predicated on this larger assumption that the use of inputs like fertilizer is low despite limited evidence that using rates higher than observed is indeed profitable for rice farmers. Furthermore, despite numerous strategies to increase rice production, average rice yields in Nigeria are quite low (said to be between 1 and 2.5 tons per hectare against potential yields of 5-6 tons per hectare) and rice farmers still rely on traditional practices (Cadoni &

[2] Though the quantity of fertilizer used in production function estimates are typically assumed to be continuous, some farmers do not use fertilizer because it is not profitable for them to do so at prevailing market prices. This makes a zero quantity of applied fertilizer an optimal choice in contrast to an unobserved quantity.

Angelucci 2013; Nwilene et al 2008). This occurs even though 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. Despite the potential for irrigated rice, we find irrigation use in our sample of rice farmers (in the main cereal root crop farming system) to be about 8 % and this is in line with previous findings, reflecting a less than 10 percent use of irrigation amongst rice producers (Liverpool et al., 2010).

One important challenge to rice production in the country is soil degradation due to poor land use practices. Historical findings of high annual depletion rates (in excess of 30 and 20 kilograms each of nitrogen (N) and phosphorus (K) respectively by Stoorvogel and Smaling (1990) have more recently been re-emphasized (Adejobi and Kormawa, 2002; Monpellier, 2013). Current practices are said to increase soil degradation, leading to desertification, salinisation, and soil and water erosion (Monpellier, 2013). Consequently, many soils in Nigeria (like many other parts of SSA are not suitable for continuous crop production without nutrient replenishment. While fertilizer use rates among rice farmers in Nigeria has traditionally been considered low (Ezui et al., 2010; Manyong et al., 2001; Ezui et al., 2008), fertilizer use appears to currently be quite common in Nigeria and not as low as conventional wisdom suggests (Liverpool-Tasie et al., 2015a; Sheahan and Barrett, 2014).

3.0 Conceptual Framework and empirical approach

Alongside non-farm or off-farm activities, agricultural production constitutes a key source of income for most rural households. While optimizing over various income earning activities, households need to decide the amount of risky inputs (such as fertilizer) to be applied on each plot[3]. As discussed in Liverpool-Tasie et al (2015a) and earlier demonstrated by Just and Pope (1979), modern inputs such as fertilizer typically increase both the mean and the variance of the net returns to production. Typically, fertilizer use decisions are taken before the rains have fully

[3] Households usually optimize, not only over all income earning activities but also at the plot level.

established or output price is known for sure. This decision on input use is also taken in the presence of imperfect credit and insurance markets. Consequently, we follow previous work to model the fertilizer use decision of a farmer as a constrained utility maximization problem as in Singh, Squire and Strauss (1986). The solution to the constrained maximization problem of an agricultural household yields reduced form specifications of input demands and technologies and output supply(Sadoulet and de Janvry 1995), The consequent input demand in a non-separable model is a function of input and output prices as well as various socio economic and household characteristics[4].

Next, to understand the effect of fertilizer use on rice yields, we use a yield response (production function) model for rice that is typically driven by agronomic principles. Here the yield on a rice plot for a farmer is a function of several vectors and can be expressed as follows:

$$Yield_{ijt} = \boldsymbol{X_{kijt}\beta} + \delta Nitrogen_{ijt} + \boldsymbol{Z_{kijt}\gamma} + u_{ijt} \qquad (1)$$

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 determinants of rice yields controlled by the farmer, including his use of other inputs. $Nitrogen_{ijt}$ (within $\boldsymbol{X_{kijt}}$) captures the quantity of applied nitrogen on the plot while $\boldsymbol{Z_{kijt}}$ is a vector of controls that affects crop production such as soil quality, access to information and markets, the level and distribution of rainfall (Tolk, Howell and Evett 1999). $\boldsymbol{Z_{kijt}}$ also includes household characteristics including the age and gender of the plot manager, household wealth. Finally, $u_{ijt} = \varepsilon_{ijt} + c_i$ is a composite error term comprising time invariant (c_i) and time varying unobserved characteristics $\varepsilon_{ijt}$of our production system while β, $\boldsymbol{\delta}$ and γ are parameters to be estimated.

Our primary interest is in estimating the extent to which nitrogen use affects rice productivity[5]. Majority of rice farmers in Nigeria either apply a compound fertilizer (NPK) as a

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[4] This motivates the variable selection for our tobit model which we specify later on in this section and use to estimate an input demand function for use in our main production function estimations.

[5] Farmers use different types of fertilizers on their plots and these fertilizers have different nutrient contents. Thus, rather than consider all inorganic fertilizer to be the same, we isolate the nutrient component of the applied fertilizer. The two major fertilizers used in Nigeria are NPK and Urea. NPK typically has about 27% Nitrogen, 13%

basal fertilizer or Urea (46% Nitrogen) as top dressing. While plants typically absorb the majority of applied nitrogen within the same season of application, the absorption process for phosphorus is much longer (Lanzer and Paris 1981; Goedeken et al.1998; Sheahan, 2012). Since rice farmers in Nigeria typically use either Urea alone or Urea and NPK, there is a high degree of correlation between the two nutrients. Thus, the yield response of rice to applied nitrogen and phosphorous application cannot be assessed separately. Furthermore, the slow take up of phosphorus makes it difficult to accurately identify the yield response to applied versus previously existing phosphorous. Consequently, this paper mostly focusses on applied nitrogen while controlling for its interaction with phosphorous[6].

Several considerations are necessary when estimating the effect of fertilizer on yields with this sort of error structure. One key issue 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 restrict any causal interpretation to the coefficient on fertilizer use in a yield response model. For example, a positive correlation between the unobserved individual effect in the error term c_i and the rate of application of nitrogen would cause an upward bias in ordinary least squares (OLS) estimators of the effect of applied nitrogen on rice yields (Hausman and Taylor 1981). A Fixed Effects (FE) model or a Correlated Random Effects (CRE) model can be used to address the endogeneity due to unobserved time invariant characteristics. The FE method attenuates potential biases by using variation in fertilizer use within a household over time to identify the causal effect of fertilizer on yields (Wooldridge, 2002). One limitation of the FE model is that we are unable to recover the coefficients on any time invariant observable characteristics as well. This can be an issue when important variables affecting yields such as soil type are time invariant. One way to address this is with the Correlated Random Effects (CRE) model. The CRE model addresses endogeneity due to unobserved time invariant factors but

Phosphorus and 13% Potassium while Urea is about 46%. For this analysis, we multiply those percentages by the total amount of each fertilizer applied to the maize plot to arrive at the total quantity of applied nutrients.

[6] Studies have also shown nitrogen to be a key constraint to rice production (Ezui et al., 2010).

still makes it possible to recover the coefficients on time invariant observed variables[7] (Sheahan et al., 2013).

While the FE and CRE models potentially address bias caused by time invariant factors (such as farmer ability that is crucial for production function estimates), they do not deal with any bias caused by time-varying unobservable factors that may be correlated with yields and also correlated with the household's nitrogen application rate. This could include plot level characteristics such as soil moisture and nutrient content which are important time-varying factors affecting yields, but typically unobserved or poorly measured. Furthermore, the amount of fertilizer applied is usually determined by the farmers expected profit maximizing objective which in turn depends on the production function, and hence ε_{ijt} (Burke et al., 2014). Thus, there could also be unobserved time varying factors that could affect both fertilizer application and yields, which(if not accounted for) could also lead to a bias on the estimated yield response to applied nitrogen.

To address this potential problem, we use a Control Function Approach (CFA) which is largely an instrumental variables method (Imbens and Wooldridge 2007, Wooldridge, 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). Imbens and Wooldridge (2007) and Wooldridge (2013) demonstrate that the CFA is more useful and flexible than IV/2SLS in such cases where nonlinear models such as Tobit are necessary. This approach distinguishes our study as most studies, estimating yield response functions, do not account for the corner solution nature of input use in crop production.

As in 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. In this article, we use the political economy of input provision to empirically identify the yield effects of fertilizer in rice production in Nigeria. The excludable instrument used in this analysis is the distance from the local government a farmer resides in, to

[7] One key assumption of the CRE model is that the unobserved household characteristic (c_i) can be modelled as a function of explanatory variables included in the model.

the local government of origin of the state governor[8]. We argue that as key politicians at the state level with notable power, governors are able to affect input allocations to curry favor or reward loyal electorate. Several studies have demonstrated how political influence affects allocation of inputs (particularly subsidized inputs) in developing countries (Mason and Ricker-Gilbert 2013; Sadanandan 2012; Chapoto 2012; Chinsinga 2012; Banful 2011 ; Pan and Christiaensen, 2012). In Nigeria, anecdotal evidence suggests that politicians patronise their district of origin by providing fertilizer and this has been demonstrated empirically (Takeshima and Liverpool-Tasie 2015). While much of the literature to 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 that has been resold in the private market (Liverpool-Tasie and Takeshima 2013). 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 to subsidized fertilizer, it may also affect the access to commercial fertilizer as well. However, 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 a priori reason why the distance of households from these local governments should independently affect the productivity of farmers in the local government for any particular crop. This is of course conditional on controlling for other factors, potentially correlated with such a distance variable (such as distance to markets or main towns) or other factors likely to affect rice yields. Consequently, this variable is considered an appropriate instrument for the CFA conditional on controlling for these other factors.

In equation (1), 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 $f_2(Nitrogen_{ijt}|Nitrogen_{ijt} > 0) = f_2(Nitrogen_{ijt})/1 - f_2(0)$[9] .

The associated likelihood function whose log is maximized can be expressed as:

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[8] 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.
9 This is multiplied by P(Nitrogen ijt)>0 to ensure that the sum of probabilities sum to one.

$$L = \prod_i \ |Nitrogen_{ijt} = 0\{f_1(0)\ \}\prod_i \ |Nitrogen_{ijt} \neq 0\left\{\frac{1-f_1(0)}{1-f_2(0)} f_2\left(Nitrogen_{ijt}\right)\right\} \qquad (2)$$

For the CFA, the exclusion restriction associated with the first part of (2) is that a subset of controls appears in our final yield response models. Following Imbens and Wooldridge (2007) and Imbens and Wooldridge (2008), we estimate a first stage regression of nitrogen use for each plot ($Nitrogen_{ijt}$) using a Tobit model. Then the generalized residual is constructed as:

$$\widehat{gr}_{ijt} = -\hat{\tau}\ 1[Nitrogen_{ijt} = 0]\ \lambda\,(-Z_i\hat{\gamma}) + 1[Nitrogen_{ijt} > 0](Nitrogen_{ijt} - Z_i\hat{\gamma}) \qquad (3)$$

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 (Imbens and Wooldridge 2008) which we estimate using the CRE.

Our instrument; distance from a farmer's LGA to the LGA or origin of the state governor is used in the Tobit models in stage 1 and then it is excluded from our estimation of equation (1). 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.

While the quadratic production function is viewed as a good approximation to the underlying functional form and is widely used in crop yield response analysis (Traxler and Byerlee 1993; Kouka et al. 1995 Sheahan et al. 2013; Liverpool-Tasie et al., 2015a), we follow Xu et al (2013) to use a linear model for this analysis. The squared quantity of applied nitrogen was never significant indicating that the quadratic model is not likely appropriate for our data. Given that the mean nitrogen application rate in our sample (about 60kg per hectare) is lower than the generalized recommendation for rice production in Nigeria of 76kg per hectare, regardless of soil type, (Ezui et al., 2010) such a linear specification is reasonable. With only about 320 observations, we carefully select control variables to control for important factors and minimise problems with multicollinearity. Though we use a linear model, we control for likely interactions between applied nitrogen and key variables in line with the literature and as relevant to the Nigerian context [10].

[10] We recognize that the use of other inputs is likely endogenous as well. However, given that our interest is on the profitability of fertilizer use (and hence the yield response estimate from the production function), we focus on addressing the endogeneity of this variable.

4.0 Data

This study is based on information from the Nigeria Living Standard Measurement Study-Integrated Survey on Agriculture (LSMS-ISA) panel data for Nigeria. This dataset contains detailed agricultural information collected at the plot and household level. The survey periods capture information from the post planting and post harvest periods of the main agricultural seasons in 2010 and 2012.. For this analysis, we extract all plots on which rice was grown in the main agricultural season in each survey year, i.e. 2010/2011 and 2012/2013. It includes plot-level information on input use, cultivation and production. Though rice is grown all across Nigeria's varied agro ecological conditions, majority of rice production takes place in the Cereal-Root Crop Farming System (C-RCFS) found in Central and Northern Nigeria. The C-RCFS found in the dry sub humid agro ecological zone is characterized by relatively lower population densities, higher temperatures and lower altitude. Due to limited observations across farming systems[11] in our dataset, this paper focusses solely on this farming system for the productivity analysis. It is the only farming system where there is consistently over 100 rice plots in each survey period.

We follow the literature in our selection of variables expected to affect rice yields. One unique feature of this study is the availability of plot level characteristics which we include in our production function estimates. This addresses some of the usually absent but important characteristics of plots that are likely to affect fertilizer use and rice yields. Given the importance of soil nutrient for crop yields directly as well as on the efficient use of applied nutrients such as nitrogen, we control for potentially different effects of main soil nutrient availability. Main soil nutrient availability is based on the soil texture, soil organic carbon, soil pH and total exchangeable bases for sequence 1 soils. We include a dummy indicating whether a rice plot had any major soil nutrient availability constraints. We also include a dummy indicating whether a farmer had any major constraints with soil nutrient retention. Soil nutrient retention is further dependent on base saturation of the soil, the cation exchange capacity of soil and the fraction of clay content. The 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, 2012). This data is at a resolution of 0.083333 dd collected at a 1:5 000 000 scale. While soil data at the local government

[11] See Liverpool-Tasie et al. (2015a) for a fuller description of the various farming systems in Nigeria.

level is less likely to be endogenous to individual farmer cropping choices, similar to fertilizer application, it is also highly variable over space and time. Thus, we consider this to be another proxy for general geographical variation that could affect fertilizer use and yields.

We also include factors that affect rice yields which are exogenous such as weather. To capture the levels and temporal distribution of rainfall in the growing season, we include the average monthly total rainfall in millimeters for the year as well as the precipitation for the wettest quarter. 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 available labor[12]. We also use a dummy to account for whether a farmer uses a chemical (herbicide or pesticide). Improved seed varieties are often a complementary input to inorganic fertilizer. Thus we include a dummy variable reflecting whether seed used was commercially purchased[13]. We also include dummy variables to indicate if a farmer is using irrigation and machinery such as a tractor. Though rice is often planted alone on a plot, we distinguish those who planted rice as a sole crop on the plot (majority of the plots) versus those engaged in intercropping. We also control for organic manure use (as an alternative source of nutrient augmentation). In all specifications, standard errors are clustered at the household level to make them robust to serial correlation and to account for non-constant variance (Wooldridge, 2002).

5.0 Results:

Table 1 describes our study sample. Average rice yields are about 3050 kgs per hectare in 2010 and 2500kg per hectare in 2012. 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 (about 5%). While the real prices of fertilizer remained relatively constant between survey periods, the average selling price of local rice increased by about 21%.

<<Table 1 goes approximately here>>

[12] This prevents a more in-depth exploration of other dimensions of nitrogen application such as increased labor demand for weeding or fertilizer application as the role that labor availability plays in the effectiveness and profitability of nitrogen application

[13] This assumes that most improved seed is hybrid which needs to be purchased each year.

5.1 Production function estimates

With the CF approach, we first estimate the factors that determine the demand for nitrogen (our endogenous variable of interest) using a Tobit model. This accounts for the corner solution nature of inorganic fertilizer input use. Table 2 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 nitrogen. The strength of the instrument in the reduced form equation is indicated by its significance at 5%; evidence that the IV is strongly correlated with the endogenous variable. As expected, farmers using complementary inputs such as irrigation, improved seeds and chemicals tend to apply more nitrogen on their rice plots. Proximity to the central market or nearest big town is also positively associated with nitrogen application. This likely captures better access to the input and lower transportation costs. Higher fertilizer price has a negative effect on demand as expected. Not surprisingly, farmers using organic fertilizer apply less inorganic fertilizer and farmers planting more than one crop tend to apply more nitrogen, likely to compensate for the competition among crops for soil nutrient.

<<Table 2 goes approximately here>>

Table 3 presents the results from the second stage estimation of the production function. . Alongside our preferred CF specification, we also present the production function estimates from the pooled OLS and CRE models which do not address endogeneity and only account for potential effects of time invariant characteristics respectively.

Applied nitrogen was interacted with the soil nutrient availability and soil nutrient retention capacity to see how rice yield response to nitrogen varies over broad soil nutrient availability and retention capacity classifications. As mentioned earlier, 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. In line with the CF approach, the generalized residual (from the Tobit model) was introduced in the model (in) to account and correct for the endogeneity of nitrogen application. Wooldridge (2014) suggests entering the generalized residual more flexibly rather than just linearly. Consequently, we include various forms of the generalized residual in the second stage estimation.

Table 3 indicates a positive and significant effect of applied nitrogen on rice yields in the C-RCFS. As expected, the seeding rate is very important for rice production. Plots at lower elevation have higher yield and higher levels of annual precipitation tend to increase yields. This indicates the importance of water for rice production. Though not statistically significant, the negative sign on rainfall stress is in line with the idea that submergence of the crop and waterlogging in deep water environment and flood prone areas can be a real source of worry to rice 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). Compared to 2010, rice yields in 2012 were significantly lower. This is likely due to the floods that affected 30 out of Nigeria's 37 States in 2012 (UNOCHA, 2012; Sidi, 2012).

Table 3 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 model which only accounts for time invariant unobserved factors appears to control for some of the endogeneity of nitrogen application (column 3 versus column 1), the difference between columns 3 and 5 in table 4 indicates the importance of correcting for time varying unobserved factors that are likely correlated with nitrogen application as well as rice yields. The various forms of the generalized residual are 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).

The MPPs were estimated using the ''margins'' command in Stata and represent the average partial effects of nitrogen on rice yields. We also calculate the APP as the change in output due to the use of applied nitrogen. This captures the gain in rice yield per unit of nitrogen compared to not applying any nitrogen. We manually calculate the APPs at the field level using the coefficients from our production function. The overall marginal effect of applied nitrogen is about 8.8. This means that an additional kilogram per hectare of applied nitrogen increases rice yields per hectare by about 8.8 kilograms, all other things being held constant. The MPPs and APPS for the C-RCFS are generally very similar and this persists across the two survey rounds (see Table 4).

<<Table 4 goes here>>

Our findings appear to be in line with some other Nigerian studies. Akighir and Shabu (2011) estimate the MPP for fertilizer in Kwande Local Government Area of Benue State, Nigeria to be 10.7. 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. Omonona et al (2012) actually find negative marginal product for fertilizer among Ofada rice producers in Ogun State in South West Nigeria. Consequently, our results tend to correspond with many of the studies indicating that the yield response to fertilizer application in Nigeria is quite low for many rice farmers.

5.2 Profitability of applied nitrogen for rice production

The estimates from the production function are then used to calculate the Expected Marginal and Average Physical Products of nitrogen rice production, EMPPs and EAPPs respectively. Our set up and analysis replicates that used by Liverpool-Tasie et al (2015a) in their study on maize. The EMPP of applied nitrogen describes how much extra rice output can be produced by using one additional unit of applied nitrogen, all else held constant. We calculate the EMPP by taking the first derivative of the production function with respect to applied nitrogen. The EAPP is calculated as the gain in rice yield per unit of applied nitrogen relative to not using any applied nitrogen (Sheahan et al, 2013). Next we use the EMPPs and EAPPs to determine the Expected Marginal Value Cost Ratio (EMVCR) and the Expected Average Value Cost Ratio (EAVCR) which are our partial profitability measures. Following Liverpool-Tasie et al (2015a), the EMVCR and EAVCR can be expressed as follows:

$$E\left(MVCR_{nijt}\right) = \frac{E(p_{rt})*E(MPP_{nijt})}{p_{nijt}} \quad (4)$$

$$E\left(AVCR_{nijt}\right) = \frac{E(p_{rt})*E(APP_{nijt})}{p_{nijt}} \quad (5)$$

where p_n is the price of nitrogen and $p_r$is the price of rice.

Liverpool-Tasie et al (2015a) find farmer behavior in rural Nigeria to be consistent with the implications of risk aversion. Consequently, and as has been done in the literature, we incorporate a risk premium of 1 to factor in risk and uncertainty and approximate for the rate at which nitrogen application is going to be profitable enough for rural farmers to be willing to use it (Xu et al., 2009; Sauer and Tchale, 2009; Bationo et al., 1992; Sheahan et al., 2013; Kelly, 2005 Anderson et al., 1977).This implies that rather than a threshold of 1 being considered necessary for the MVCR and AVCR values to indicate profitability for a risk neutral farmer, a higher MVCR of 2 is considered to be necessary for a risk averse farmer to find nitrogen application profitable. This also addresses the fact that fertilizer use also has other cost implications for rice production. For example, higher fertilizer use is typically associated with increased weed prevalence and a consequently higher labor cost for weeding, in addition to that needed for its application[14].

With the relatively low MPP of nitrogen for rice production, the proportion of rice plots for which nitrogen application is profitable (for a risk averse farmer) at the observed fertilizer acquisition prices and rice selling price is quite low. In 2010/2011, it is only profitable for about 7% of all rice plots. (Table 5). We explore various scenarios to explore how the profitability of nitrogen application varies with key profitability considerations such as the price of rice, transportation costs, yield response values and fertilizer subsidy.

5.3 The effect of rice prices on the profitability of nitrogen application

The output price is key for any profitability analysis. The output price used for this analysis was the farmer selling price for all rice selling households. For households not selling any rice, the median selling price of rice per kilogram among sellers in their community was used. While it is likely that a farmer's decision to use fertilizer during the planting season is driven by expected prices of rice rather than the actual price at post planting or post-harvest, the unavailability of consistent price information over time at the community or Local Government Area (LGA) level precluded our ability to explore options to generate such expected prices as described in Muyanga

[14] Rice bran is a residue from rice production that can be used, for example, as flooring for poultry farmers. Though this residue could potentially be an additional source of revenue to rice farmers, anectdotal evidence indicates that it is usually a nuisance, (to) farmers often offered at no fee to(willing) consumers (such as poultry farmers) willing to clear and haul the residue away from the farm.

(2013) and used by Sheahan et al. (2013). By using the selling price, we are assuming farmers had a good sense of those prices at planting time. We replace any further missing rice price values with the median selling price of rice among sellers in the same local government and then state when LGA medians are unavailable[15].

Though nitrogen application was only profitable for about 7% of rice plots in 2010, this number is much higher in 2012 at 12%. These differences across the years appear to be partly driven by the increase in the price of rice over the two years[16]. Figure 1 shows that rice prices increased between 2010 and 2012. Using data on rice prices over time from the National Bureau of Statistics, the average price for local rice increased by about 19% between 2010 and 2012. The change in the mean price of rice in our study sample over the two survey rounds is similar at 21%. This indicates the importance of the price of rice in the profitability of rice production in Nigeria.

<<Figure 1 goes approximately here>>

We find significant variation between the selling prices reported by farmers and the retail prices in the community. This appears to be driven by the form in which rice is sold. According to the Nigerian Agricultural Markets Information System (NAMIS), the average price for local rice paddy in 2011 (corresponding to the post-harvest period in our survey sample) was N69 per kilogram. This is close to our sample average for 2011, which was N64 per kilogram. However, the retail price for local rice in our communities was much higher (more than double the average selling price) at about N155 and N180 for 2011 and 2013 respectively. This indicates that there is significant value added from processing the local rice paddy into finished rice. While an analysis on the cost of conversion is necessary to determine the true profitability effects, it is not likely that the conversion cost from paddy to finished rice (per kilogram) completely explains this margin. This indicates that there is likely some potential to improve the benefits accrued by rice farmers (in terms of price) and hence the profitability of fertilizer use for its production. Table 6 reveals the average output /input price ratios for the selling price received by farmers and the different retail rice prices in rural communities. The output input price ratio increases by over 200% when the selling price is considered versus the community retail price. We ran various simulations to

[15] We also run all our profitability estimates using the median community selling price for rice and these do not change the study findings.

[16] All rice and input prices are adjusted to 2012 prices using the cpi from the Nigerian National Bureau of Statistics

see how the profitability of fertilizer use would change if the community prices were what farmers received. We find that with the retail price in the community (more than double the selling price), the percentage of plots on which nitrogen application is profitable tripled in 2012 from 12% to about 70% (See Figure 2).

<< Table 6 goes approximately here>>

<< Figure 2 goes approximately here>>

Finally, national rice policies play a particularly important role in Nigeria. To protect its domestic industry, Nigeria restricts the quantity of rice imported. It uses various strategies including quotas and tariffs. Beginning in 2013, import tariffs on milled rice increased to 110 percent. The extent to which these policies affect local prices is an important question. While price transmission might not be complete, our data indicate that imported rice fetches a premium in rural communities. This might indicate some quality differences preventing local rice from being a perfect substitute in consumption with imported rice. This poses another opportunity (whose cost implications must be studied) for increasing the output price received by farmers and the consequent profitability of fertilizer use (figure 2). Ultimately, our analysis demonstrates the importance of the price of rice for the profitability of nitrogen application in Nigeria.

5.4 The effect of fertilizer acquisition costs on the profitability of nitrogen application

The majority of fertilizer used for rice production in Nigeria is either NPK or Urea. Consequently, the price used for nitrogen is a simple average of the market price of the nitrogen components of Urea and NPK converted to a one kilogram equivalent (Xu, 2008; Sheahan et al. 2014). We consider both the acquisition cost and the market price of nitrogen to account for the role of high transportation costs in the profitability of nitrogen application (Sheahan et al. 2013; Liverpool-Tasie et al., 2015). We calculate the fertilizer acquisition cost to be the market price for nitrogen plus the cost of transportation from the market to the farm gate (Sheahan et al. 2013). Transportation costs to acquire fertilizer are very high in Nigeria. Liverpool-Tasie et al (2015a) found that about 70% of the actual cost incurred by farmers using fertilizer is due to transportation cost. When using the subset of rice plots, we find very similar results. These high transportation costs were also observed in rural Ethiopia where farmers living about 10km away from a distribution center faced transaction and transportation costs (per unit) that were as large as the costs needed to bring fertilizer over about a 1,000km distance from the international port to the input distribution center (Minten et al., 2013)

To explore the effects of transportation costs on the profitability of nitrogen application, we simulate how reducing transportation costs affect the number of plots on which nitrogen application is profitable. We find that reducing the transportation costs associated with securing fertilizer by 50% increases the percentage of plots on which nitrogen application would be profitable in the C-RCFS by 175% in 2012.A further reduction of transportation costs by 75% would just about quadruple the percentage of rice plots on which nitrogen application would be profitable. This indicates that while the low profitability of nitrogen application in the main C-RCFS is partly driven by the low MPP of nitrogen, reducing the cost of fertilizer acquisition can significantly improve the profitability of nitrogen application for rice production in this farming system. These are really large effects and we consider these, conservative estimates[17]. These results echo the findings of Minten et al. (2013) on the huge role that transportation cost play in the adoption of improved technologies in Ethiopia.

5.5 The effect of fertilizer subsidies on the profitability of nitrogen application

Given the importance of fertilizer subsidies in Nigeria, we also consider the effect of reducing input prices with a fertilizer subsidy. We simulate the likely effect of subsidized fertilizer on the profitability of nitrogen application for rice farmers using the range of 25% to 50% that is likely given the government program in operation. See (Liverpool-Tasie et al (2015a), Takeshima and Nkonya (2014) and Liverpool-Tasie and Takeshima (2013) for more details on the fertilizer subsidy program in Nigeria.

Table 7 reveals that reducing the price of fertilizer increases the number of plots on which nitrogen application is profitable in the C-RCFS. If the fertilizer program was to have reached all rice farmers with a 50% subsidy, this would have increased the number of plots on which nitrogen

[17] Using the winsorized but uncapped transportation costs we find that a 50% reduction in transportation costs could increase the percentage of plots for which fertilizer use is profitable by much larger fractions than presented in table 7

application was profitable from 12% of total rice plots to 32% in C-RCFS[18]. In reality, not all farmers actually receive subsidized fertilizer and so the likely effect of the 50% subsidy (depicted in table 7) will be much lower than 32%. Attempts to reduce the transportation costs for fertilizer acquisition (such as infrastructure improvements or programs to encourage the setup of retail depots within communities or in smaller towns) are likely to have a larger effect. Besides, such improvements in infrastructure and access to fertilizer benefit all farmers in the community compared to a fertilizer subsidy for which access is less likely to be universal.

<< Table 7 goes approximately here>>

5.6 The effect of increasing the rice yield response of applied nitrogen on profitability

The third main factor that drives the profitability of an input is the yield response of the input. In our study sample, the marginal physical product of applied nitrogen for rice production in the main cereal-root crop farming system was about 8.9 kilograms of rice per hectare for each kilogram of applied nitrogen per hectare. Table 8 shows that at the observed acquisition costs and selling price of rice, if the MPP of applied nitrogen was higher at 15kg per hectare of rice for each kilogram per hectare of applied nitrogen, this would increase the percentage of plots on which applied nitrogen was profitable for a risk averse farmer; from 7 percent to 27 percent. The application of nitrogen would be profitable for about 80% of rice plots (even at the current high acquisition costs of fertilizer) if the MPP of applied nitrogen was at 30 (similar to rates found on field trials or from the experience in Asia) - see Figure 3. This indicates the importance of the yield response to nitrogen application in the profitability of fertilizer use; a factor not often highlighted in the literature. Further analysis of issues around soil quality and management practices (timing of application, use of complementary inputs) are necessary to raise these response rates.

<< Table 8 goes approximately here>>

Figure 3 goes approximately here >>

[18] It should be noted that our simulated profitability effects overestimate the likely impact of subsidies since we assume that all farmers would receive these subsidies and don't restrict the quantity of subsidized fertilizer each farmer can receive

5.7 Fertilizer profitability and observed use rates

Finally, we compare actual observed fertilizer use rates on rice plots in Nigeria with the expected profit maximizing levels. Following Sheahan et al. (2013) we 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 2 (for a risk averse farmer). Comparing actual nitrogen application rates on rice plots to expected profit maximizing rates indicates that fertilizer use for rice is often higher than expected profit maximization for risk averse farmers would indicate. Table 9 reveals that the mean observed application rate of nitrogen for farmers (assuming they are risk averse) is consistently higher than the mean expected profit maximizing level. At the plot level, however, we see that only 4% of farmers in the C-RCFS apply less than the amount of nitrogen one would expect a profit maximizing risk averse farmer to apply. There are no farmers in our sample who are not using fertilizer but would be expected to, given their AVCR or MVCR.

<< Table 9 goes approximately here>>

6. Conclusions

This article looked at the effect of nitrogen application on rice production in Nigeria. Using the LSMS-ISA panel data for 2010/2011 and 2012/2013, we explore the effects of nitrogen application on rice yields for the main cereal-root crop farming system (that accounts for about 70% of rice plots in the study sample). We use an instrumental variable approach within a panel data framework to address the endogeneity and corner solution nature 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 is quite low, at about 9 kilograms. High transportation costs and low selling price for rice significantly reduce the profitability of fertilizer use. Reducing transportation costs could more than quadruple the percentage of plots for which fertilizer use is profitable for rice farmers in the main cereal-root crop farming system. As in Liverpool-Tasie et al (2015a), we also find that while both subsidizing the price of fertilizer and reducing transportation costs could increase the profitability of using the input, reducing transportation costs will likely have a much larger impact since the effects of infrastructural improvements and access to fertilizer tend to be more universally spread, compared to fertilizer subsidies. Reducing transportation costs by half or three-quarters could increase the percentage of plots in the main cereal farming system (C-RCFS) for which fertilizer use is profitable by about 175% and over 200% respectively. Linking farmers to input suppliers is likely to have huge impacts on the profitability of fertilizer use in rural Nigeria. For example, innovative schemes by the private sector which use industrious farmers within communities to serve as village promoters (teaching farmers about new technologies and also selling inputs) could further reduce transportation costs and increase the expected profitability of fertilizer use for many rural farmers (Liverpool-Tasie et al., 2015b). Rice prices is another key issue in the profitability of fertilizer use. Selling prices for local rice are extremely low in rural Nigeria and this also significantly reduces the profitability of fertilizer use. Improved rice quality and other mechanisms to increase the fraction of the retail price of rice in rural areas will go a long way to increase the profitability of fertilizer use.

To address the challenges associated with the trend of increasing rice imports, the Nigerian government recently introduced several policies to stimulate local rice production. Alongside the usual trade restrictions, other policy reforms have been introduced to deregulate sub sectors like fertilizer and seed and to coordinate demand and supply of rice. These reforms alongside others geared to improve infrastructure might change some of our findings which could serve as a basis for evaluating such programs.

Our results indicate that the application of nitrogen could be expanded for certain farmers in Nigeria. In addition to transportation costs, improving the fraction of the retail price of rice captured by farmers is key. The marginal production of applied nitrogen is quite low. This indicates that there is a need to understand and improve the yield response of applied nitrogen to expand fertilizer use in this area. This could be through complementary practices (such as irrigation facilities, good quality seed and other more efficient methods of fertilizer use or crop management practices).There is also likely a significant role for extension and other innovatively structured mechanisms to disseminate agronomic best practices to rural farmers.

Generally, this study confirms that fertilizer use which is clearly evident in rice production in Nigeria can be profitable[19]. However, at current input and output prices, this remains a reality

[19] 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.

for only a subset of rice farmers. Expanding the number of rice farmers that use fertilizer (and for which it is economically profitable at acquisition price) is still necessary in Nigeria. Currently about 60% of rice plots use fertilizer. Nitrogen application among rice farmers is consistent with expected profit maximization in many cases. We do not find any farmers for whom applied nitrogen is profitable that are not using fertilizer in the study sample for each survey year.

This study only focusses on rice but confirms findings in Liverpool-Tasie et al (2015a) for maize and Liverpool-Tasie et al (2015) on sorghum raises issues that are likely to affect fertilizer use for other crops[20].

[20] Though capturing the main rice growing areas, our study only focuses on the cereal-root crop farming system due to data limitations. The likely variation in the yield effect and profitability of fertilizer across agro ecological conditions indicates a need for some analysis on the other farming systems where rice production is important.

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Table 1 Descriptive statistics for key study variables

Variables	2010		2012	
	Mean	Std. Dev.	Mean	Std. Dev.
Household adult equivalency units (units)	5.522	2.485	6.133	2.687
Rice yield per hectare (kilograms)	3,049	3,024	2,556	2,380
Nitrogen applied per hectare (kilograms)	61.66	86.49	59.11	91.72
Seeding rate (kilograms per hectare)	15.95	28.05	47.62	33.43
Organic Fertilizer	0.0148	0.121	0.0172	0.131
Commercial seed	0.192	0.395	0.190	0.393
Male plot manager (1/0)	0.941	0.236	0.931	0.254
Mechanization (0/1)	0.187	0.391	0.103	0.305
Herbicide use (1/0)	0.611	0.489	0.621	0.487
Area planted (hectares)	0.612	0.377	0.614	0.476
Plot elevation (meters)	303.5	225.8	318.5	215.3
Precipitation of wettest quarter	676.5	80.09	660.2	77.64
One other crop planted	0.172	0.379	0.109	0.313
Two other crop planted	0.0591	0.236	0.0690	0.254
Three or more other crop planted	0.0936	0.292	0.0690	0.254
Age of plot manager (years)	46.12	14.54	46.29	13.59
Phosphorus applied per hectare (kilograms)	13.35	26.54	13.33	26.33
Assets (Thousand Naira)	122.9	387.5	124.2	183.5
Rice selling price (Naira per kilograms)	63.37	30.11	78.29	42.69
Fertilizer price (Naira per kilograms)	97.26	36.65	99.05	42.47
Nitrogen price (Naira per kilograms)	284.41	94.35	314.37	88.87

Source: Authors calculations using LSMS-ISA data (2010/2011 and 2012/2013). All prices are adjusted to 2012 prices using the cpi from the Nigerian National Bureau of Statistics

Table 2. Tobit results of the determinants of nitrogen application rates

	Coefficients	P value
Distance to the local government of origin of the governor (Km)	-0.325**	0.032
Commercial seed	28.156	0.138
Seed rate (kg/hectare)	-0.043	0.887
Labor (adult equivalency units)	5.163	0.160
Irrigation (0/1)	79.649***	0.005
Mechanization (0/1)	19.641	0.539
Herbicide use (0/1)	65.893***	0.001
Sex (0/1)	8.793	0.770
Age (years)	-0.961	0.119
Assets ("000 Naira)	0.023	0.337
Plot area (hectares)	-298.290***	0.000
Plot area squared (hectares)	99.467***	0.000
One other crop planted	19.182	0.405
Two other crop planted	51.492*	0.056
Three or more other crop planted	63.206**	0.026
Plot Elevation (m)	0.023	0.800
Average 12-month total rainfall(mm) for Jan-Dec	-0.063	0.549
Precipitation of wettest quarter	0.156	0.479
Organic fertilizer (0/1)	-81.521	0.129
HH Distance in (KMs) to Nearest Market	-0.624**	0.033
HH Distance in (KMs) to Nearest Big Town	-0.364***	0.001
Price of Nitrogen (N/Kilogram)	-0.174***	0.007
Price of rice (N/Kilogram)	0.012	0.964
Moderate/severe soil nutrient constraints	1.111	0.971
moderate/sever challenges with soil nutrient retention capacity	0.073	0.998
2012 (1/0)	-45.370	0.324
Regional dummies included	-16.962	0.376
Mean of time varying decision variables included	YES	
Number of observations	253.412*	0.058
Joint significance of regressors (p>chi2)	0	

, ** and * are significant at 10,5and 1 percent respectively. + is significant at 15% or less.*

Table 3. Production function estimates

	Pooled OLS		**Controlling for time invariant unobserved factors**		**Controlling for both time varying and invariant factors**	
	Coefficient	p value	Coefficient	p value	Coefficient	p value
Nitrogen	8.585***	0.000	5.721^{+}	0.121	9.278*	0.089
Phosphorus	1.886	0.898	0.582	0.969	-7.709	0.637
Nitrogen*Phosphorus	-0.006	0.922	-0.005	0.944	-0.021	0.766
Seed rate (kg/hectare)	11.251**	0.028	13.940***	0.008	12.888**	0.049
Moderate/severe nutrient constraint	697.118	0.315	482.595	0.522	848.526	0.280
Moderate nutrient constraint*Nitrogen	-5.742	0.208	-5.330	0.235	-3.616	0.437
Moderate/severe nutrient retention constraints	-1,259.18	0.159	-886.685	0.352	-578.953	0.530
Moderate/severe nutrient retention constraints*Nitrogen	11.643*	0.052	10.773*	0.078	6.265+	0.113
Commercial seed	170.725	0.635	490.498	0.505	267.961	0.753
Irrigation	-906.354	0.225	-883.802	0.470	-547.001	0.691
Mechanization (0/1)	941.011	0.193	413.796	0.751	388.774	0.792
Organic fertilizer (0/1)	1,017.45	0.122	-1,593.939	0.188	-1,146.800	0.508
Labor (adult equivalency units)	-57.685	0.342	-82.142	0.242	-76.861	0.239
Sex (0/1)	25.062	0.976	111.891	0.891	105.142	0.885
Age (0/age)	15.133	0.229	8.472	0.725	3.528	0.949
Herbicide (0/1)	-413.922	0.188	-764.885	0.188	-615.976	0.342
Average 12-month total rainfall(mm)	0.544	0.712	2.030	0.238	2.294+	0.101

Precipitation of wettest quarter	-3.152	0.401	-1.397	0.712	-2.888	0.497
Plot elevation (m)	-3.219**	0.023	-4.267**	0.016	-3.132*	0.091
Plot area (hectares)	-5,761.123***	0.000	-6,982.866***	0.000	-5,818.082***	0.000
Plot area squared (hectares)	1,866.327***	0.000	2,081.715***	0.000	1,846.996***	0.000
One other crop planted	-933.141**	0.016	-78.342	0.918	-322.906	0.743
Two other crop planted	-785.312	0.152	409.363	0.659	161.590	0.884
Three or more other crop planted	-613.595	0.305	1,589.591	0.218	1,089.419	0.407
Assets ("000 Naira)	1.019***	0.000	0.575*	0.076	0.759	0.828
2012	-998.779***	0.001	-977.989***	0.003	-612.908*	0.061
CRE controls (mean of all time varying variables) included	NO		YES		YES	
Other controls included*			NO		YES	
Residual included in production function			NO		YES	
Generalized residual					-13.272	0.898
Generalized residual squared					403.437**	0.038
Number of observations	323		323		323	
R squared	0.436		0.462		0.524	

, ** and * are significant at 10,5and 1 percent respectively. + is significant at 15% or less.*

Table 4: MPPs and APPs of applied nitrogen

	MPP	APP
2010	8.78**	8.51
2012	8.86*	8.63

, ** and * are significant at 10,5and 1 percent respectively. + is significant at 15% or less.*

Table 5 Transportation costs and the profitability of fertilizer use in the cereal-root crop farming system

Proportion of rice plots for which fertilizer use is profitable for a risk averse farmer (MVCR>=2)				
	Full acquisition cost	**Transportation cost reduced by 50%**	**Transportation costs reduced by 75%**	**No transport cost-Fertilizer available in the village**
2010	0.07	0.20	0.32	0.55
2012	0.12	0.33	0.44	0.62

Source: Authors estimations from the LSMS-ISA data. These results are gotten from a simulation of fertilizer profitability with different transportation cost.

Table 6: Price ratios across rural communities

Selling price of rice/ Nitrogen	0.26
Community retail price of local rice/ Nitrogen	0.81
Community retail price for imported rice/ Nitrogen	1.01

Source: Authors estimations from the LSMS-ISA data, Prices are adjusted to 2012 prices using the CPI from the Nigerian National Bureau of Statistics.

Table 7 The effect of subsidizing fertilizer on the profitability of fertilizer use for rice production

	Full price	25% subsidy on fertilizer price	50% subsidy on fertilizer price
2010	0.07	0.12	0.17
2012	0.12	0.18	0.32

Source: Authors estimations from the LSMS-ISA data and based on production function estimates

Table 8. The effect of increasing the yield response (marginal physical product-MPP) of applied nitrogen

The proportion of rice plots for which fertilizer use is profitable for a risk averse farmer					
	Current MPP at 8.6	MPP of 15	MPP of 20	MPP of 25	MPP of 30
2010	0.07	0.27	0.59	0.69	0.75
2012	0.12	0.39	0.60	0.71	0.79

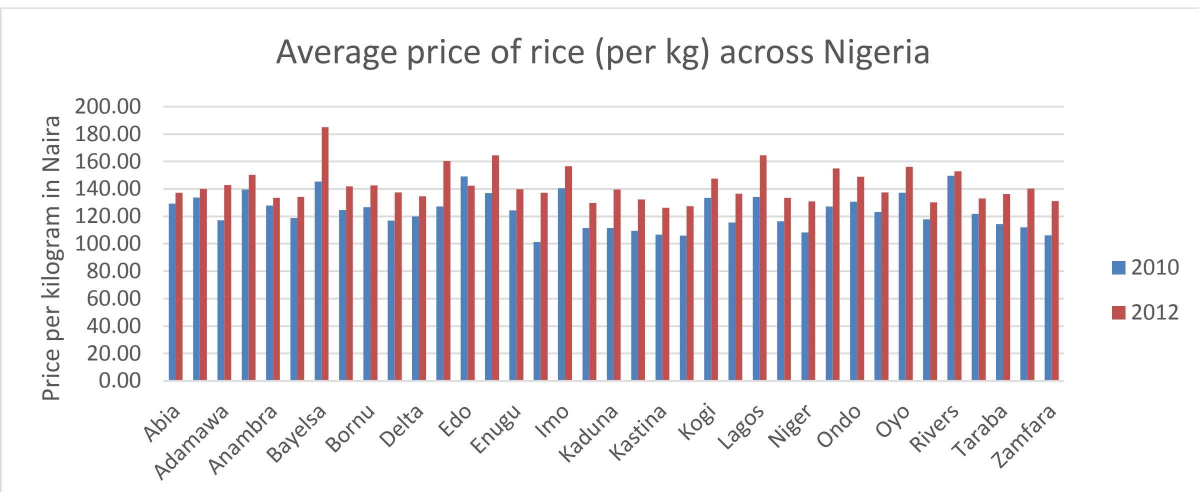
Source: Authors estimations from the LSMS-ISA data. These results are gotten from a simulation of fertilizer profitability with different transportation cost.

Table 9: A comparison of actual and expected profit maximizing nitrogen application rates for rice in Nigeria for risk averse farmers

	Percentage of plots not applying nitrogen	Percentage of plots not applying nitrogen for which it would be profitable (AVCR>=2)	Mean optimal nitrogen application rate (kg)	Percentage of plots whose use of nitrogen application rate is less than optimal given expected profitability
2010	36%	0%	12.97	**4%**
2012	39%	0%	10.29	**5%**

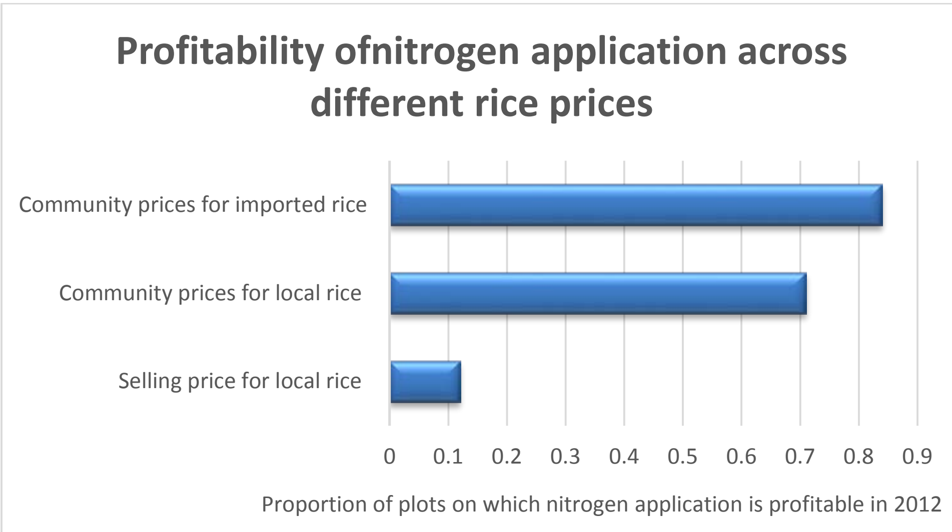
Source: Authors estimations from the LSMS-ISA data and based on production function estimates

Figure 1:



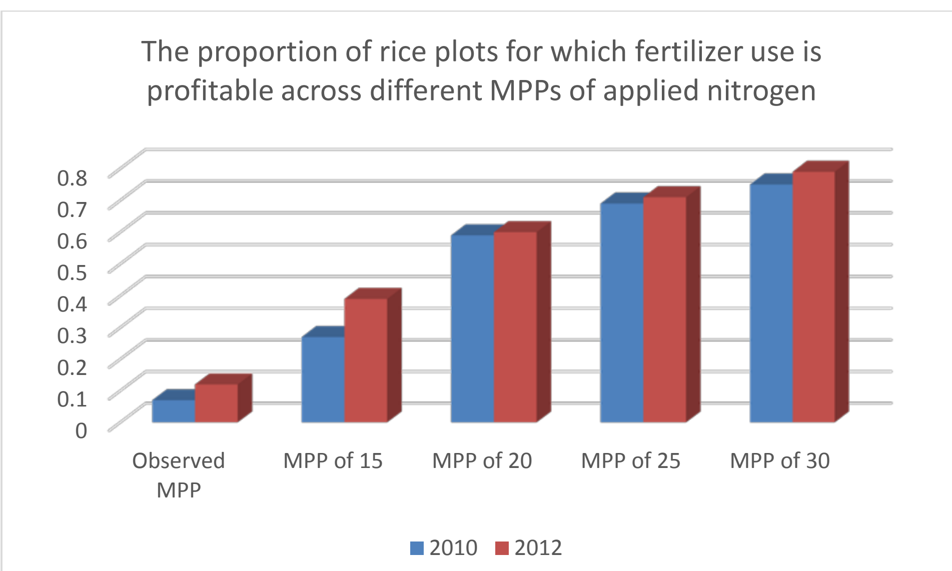
Source: Authors estimations with data from the Nigerian National Bureau of Statistics

Figure 2



Source: Authors estimations from the LSMS-ISA data

Figure 3



Source: Authors estimations from the LSMS-ISA data