Is fertilizer use inconsistent with expected profitability in Sub Saharan Africa? The case of rice in Nigeria

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Abstract

This article revisits a conventional wisdom that inorganic fertilizer use across sub-Saharan Africa is too low. This expectation that more farmers should be using inorganic fertilizer and at higher rates implies it is profitable to use rates higher than observed if farmers are rational expected profit maximizers. The article exploits the political economy of fertilizer access in Nigeria to get consistent estimates of the effects of applied nitrogen on rice production. We find the yield response to applied nitrogen to be low in the main rice growing farming system. Farmer behavior is not inconsistent with expected profitability which is limited by a low yield response to applied fertilizer, high transportation costs and low selling prices for rice in rural areas.

Key words: Fertilizer profitability, Rice, Marginal physical product, Political economy, Nigeria, Africa

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Introduction

Despite a widely accepted view that increased use of modern inputs such as 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; The Montpellier Panel, 2013; Jayne and Shahid, 2013). The reasons offered to explain low adoption and use 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), low soil carbon content (Marenya and Barrett, 2009), farmer motivation and procrastination issues (Duflo et al., 2008; 2009), riskiness and credit constraints (Feder et al. 1985; Croppenstedt et al. 2003).

These factors (often considered alone) are closely related and jointly affect the profitability and consequent use of inorganic fertilizer in Sub Saharan Africa (SSA). Thus, the notion that fertilizer use in SSA is "too low" needs to be assessed within a framework that confirms if it is profitable to use rates higher than is currently observed[1]. Rigorous empirical evidence to determine this is limited. Many profitability studies are dated or based on particular case study areas (Kelly et al., 2005; Wopereis-Pura et al., 2002; Poussin, et al., 2003; Becker and Johnson, 1999; Duflo et al., 2008). Furthermore, few address the endogeneity of the fertilizer use decision (Adedeji et al., 2014; Offodile, 2010; Omonona et al., 2012; Akighir and Shabu, 2011)[2] or have compared actual farmer fertilizer use behavior to those expected of profit maximizing rural households while taking risk preferences and transportation costs into consideration. Thus this article contributes to the limited literature by combining information on fertilizer agronomics (rice yield response to applied fertilizer) 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 the endogeneity of the nitrogen application decision due to both time invariant and varying unobserved factors. We exploit the political economy of fertilizer access in Nigeria to empirically estimate consistent

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[1] While we recognize that fertilizer use could be considered too low from a purely agronomic perspective, this article focusses on the profitability perspective which takes into account both the agronomics and economics of fertilizer use.

[2] Exceptions include Duflo et al., 2008, Sheahan et al. 2013 and Liverpool-Tasie et al., 2015a.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 potential effect of time varying unobservable factors.

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 compare fertilizer use behavior associated with expected profit maximization (under various assumptions about the risk preferences of smallholder farmers) to the behavior of rice farmers in our sample.

We find that the yield response to applied nitrogen for rice production in our sample is low at about 9kgs of rice for each additional kilogram of applied nitrogen. Our results are consistent with studies which found a linear relationship between applied nitrogen and rice yields (Kamara et al., 2011; Ekeleme et al., 2010; Witt et al.,1999) but with much lower yield response than the 19-78kg found for irrigated rice in field trials in the Senegal river valley (Haefele and Wopereis, 2005)[3]. The results echo suggestions by many rice studies in the region of the importance of organic matter, soil acidity, water and other management practices on the efficiency of inorganic fertilizer use (Becker and Johnson, 2001; Haefele and Woperieis, 2005; Haefele et al., 2003; Haefele et al., 2004; Tanaka et al., 2013; Poussin et al., 2003; and Yamaguci, 1999)[4].

The article makes several contributions to the literature on fertilizer use in SSA. The first is that it contributes to the limited empirical evidence exploring the popular notion that fertilizer use is *too low* for rational profit maximizing farmers in SSA. The second contribution is that the article 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. The article extends their work by applying a modeling approach that is more appropriate in a context (input use for crop production) where endogeneity and corner solutions are key characteristics[5].

The fourth contribution the article makes is the focus on a different crop; rice, since most of the current literature has focused on maize (Xu et al. 2009; Sheahan et al., 2013; Snapp et al,

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[3] Majority of the rice production in our sample is rainfed with just about 8% of farmers using irrigation.
[4] While not directly comparable to studies on maize given the different cropping systems, we do find evidence that the yield response to applied nitrogen for rice in Nigeria is quite low as was found for maize (Liverpool-Tasie et al., 2015a) but lower than that found for maize in parts of East and Southern Africa (Sheahan et al., 2013; Marenya and Barrett, 2009; Matsumoto and Yamano, 2011;Xu et al., 2009)
[5] 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.

2014; Liverpool-Tasie et al., 2015a). Rice is an extremely important crop serving as the staple food for over half the world's population (IRRI, 2013). It is critical to food security providing up to half of the dietary caloric supply for millions living in poverty in Asia. Rice is also an important food staple in Latin America and Africa, In SSA alone, rice consumption among urban dwellers has consistently grown, doubling since 1970 (Muthayya et al., 2014).

Nigeria is a major importer of rice. This is driven by population growth, urbanization and a preference for rice, which has 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 such as seeds and fertilizer (FMARD, 2011). This strategy is predicated on the larger assumption that the use of inputs such as 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 and Angelucci 2013; Nwilene et al 2008). This occurs even though Nigeria is endowed with favorable ecologies for rice cultivation.

The rest of the article is organized as follows. Section 2 describes rice production and fertilizer use therein for Nigeria. Section 3 describes the data used while section 4 presents our conceptual framework and empirical methods. Section 5 presents and discusses our results. This includes the determinants of nitrogen application among rice farmers, 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. Fertilizer use for rice production in Nigeria

Various rice production systems and growing ecologies exist within Nigeria. They include: Upland (Rain Fed and Irrigated), Hydromorphic (flooded fields), 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 low at about 8 %, in line with previous findings reflecting a less than 10% use of irrigation amongst rice producers (Liverpool et al., 2010).

One important challenge to rice production in Nigeria 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; The Montpellier Panel, 2013). Current practices (including continuous cropping and limited use of organic fertilzers, cover crops and other practices which build up soil organic content) are said to increase soil degradation, leading to desertification, salinisation, and soil and water erosion (The Montpellier Panel, 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 from studies focused on particular areas (Ezui et al., 2010; Manyong et al., 2001; Ezui et al., 2008), more recent studies based on nationally representative data indicates that fertilizer use is quite common in Nigeria and not as low as conventional wisdom suggests (Liverpool-Tasie et al., 2015a; Sheahan and Barrett, 2014). In a context where governments are spending large amounts of scarce resources on programs to increase modern input use (particularly fertilizer subsidies) to improve crop productivity, it is important to understand if some of the underlying assumptions/factors necessary to maximize the impact of the programs are in place[6]. One key factor that this article explores is whether rice farmers have a high marginal productivity and value product of fertilizer use.

3. Data

This article is based on information from the Nigeria Living Standard Measurement Study-Integrated Survey on Agriculture (LSMS-ISA) panel data for Nigeria. This dataset is nationally representative and 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

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[6] Liverpool-Tasie and Takeshima (2013) provide a good description of some key factors necessary for fertilizer subsidies to increase farmer use of the product for productivity growth.

2012/2013. The data includes plot-level information on input use, cultivation and production. The LSMS-ISA dataset includes geo-referenced plot locations and Global Positioning System (GPS)-based plot areas. 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[7] in our dataset, this article focusses solely on the C-RCFS the productivity analysis. It is the only farming system where there is consistently over 100 rice plots in each survey period. Thus our results are not nationally representative but can be considered representative of the main farming system for rice production in Nigeria.

Fertilizer use in our sample is quite high, applied on over 60% of rice plots. Conditional on use, rice farmers tend to apply about 350kg of fertilizer per hectare. Though consistent with the high rates of fertilizer application in Nigeria from other studies using the same data (Sheahan and Barrett, 2014; Liverpool-Tasie et al., 2015a), this application rate is higher than the national average (of about 310kg/hectare) gotten when using the same dataset (Sheahan and Barrett, 2014). This might indicate that higher levels of inorganic fertilizer is used for rice versus other crops such as cassava and maize. Average rice yields in our dataset are about 3 tons per hectare in 2010 and 2.5 tons per hectare in 2012[8]. 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 20%[9] (Table 1).

<<Table 1 goes approximately here>>

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[7] See Liverpool-Tasie et al. (2015a) for a full description of the various farming systems in Nigeria applied in this study.

[8] The yields in 2010 are higher than the typically quoted range of 1-2.5 tons per hectare while those for 2012are within the range and this might be due to time specific factors.

[9] We notice a significant increase in the rice seeding rate over the survey years which is surprising. While we are not able to confirm is this is due to data quality issues or some significant change between rounds, we run our production function estimates with and without the seeding rate to confirm that our main results on our key variable of interest are not affected.

4. 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[10]. As discussed in Liverpool-Tasie et al (2015a) and earlier demonstrated by Just and Pope (1979), fertilizer use typically increases both the mean and the variance of the net returns to production. Typically, fertilizer use decisions are taken before the rains have fully 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 conceptualize the fertilizer use decision of a farmer as the solution to a constrained utility maximization problem of an agricultural household as in Singh, Squire and Strauss (1986). The solution yields reduced form specifications of input demands and technologies and output supply (Sadoulet and de Janvry, 1995). Input demand is thus a function of input and output prices as well as various socio economic and household characteristics[11].

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

$$Yield_{ijt} = \boldsymbol{X_{kijt}\beta} + \delta QNitrogen_{ijt} + \boldsymbol{Z_{hijt}\gamma} + u_{ijt} \tag{1}$$

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 apart from fertilizer. $QNitrogen_{ijt}$ captures the quantity of applied nitrogen on the plot while $\boldsymbol{Z_{hijt}}$ 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). $\boldsymbol{Z_{hijt}}$ also includes household characteristics including the age and gender of the plot manager,

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[10] Households usually optimize, not only over all income earning activities but also at the plot level. Sheahan et al., 2013; Liverpool-Tasie et al, 2015a)

[11] 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.

household wealth. Finally, $u_{ijt} = \varepsilon_{ijt} + c_i$ is a composite error term comprising time invariant (c_i) and time varying unobserved characteristics ε_{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[12]. Majority of rice farmers in Nigeria either apply a compound fertilizer (NPK) as a 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. For this reason (among others), studies on fertilizer yield response to cereals generally focus on Nitrogen (Sheahan et al., 2013; Liverpool-Tasie et al., 2015a; Ezui et al., 2010., Burke, 2014). This article also focusses on applied nitrogen while controlling for its interaction with phosphorous and noting the omitted variable bias this might introduce.[13] Since basal fertilizer is usually applied before seeding for upland rice (and before transplanting for lowland rice) while top dressing is applied after the rice plant has germinated (and at or after transplanting, where applicable), controlling for this interaction may reflect the time of fertilizer application and/or whether farmers apply both basal and top dressing fertilizer.

Several considerations are necessary when estimating the effect of fertilizer on yields with the error structure of equation 1. 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

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[12] 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% 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.

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

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 still makes it possible to recover the coefficients on time invariant observed variables[14] (Wooldridge, 2010; 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. 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, 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 (IV) 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). This is important because fertilizer use represents an observable outcome by a farmer where the use variable takes a zero value with positive probability but is largely continuous over strictly positive values.

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[14] 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.

For the CFA, we estimate

$$E\big(Yield_{ijt}|QNitrogen_{ijt}, Z, r\big) = E\big(Yield_{ijt}|QNitrogen_{ijt}, Z_{\mathbf{1}}\big)$$

$$= \varphi(Y\beta) \tag{2}$$

$$QNitrogen_{ijt} = Z\theta + v, \tag{3}$$

where Y is a general and nonlinear function of the quantity of applied nitrogen ($QNitrogen_{ijt}, Z_1$), r is an omitted variable which is correlated with $QNitrogen_{ijt}$ Z remains as previously defined and θ and β are estimable parameters . The exclusion restriction associated with the first part of (2) is that a subset of controls (Z_1) appears in our final yield response model $E\big(Yield_{ijt}|QNitrogen_{ijt}, Z, r\big)$. Following Imbens and Wooldridge (2007) and Imbens and Wooldridge (2008), we estimate a first stage regression of nitrogen use ($QNitrogen_{ijt}$) for each plot using a Tobit model. Then the generalized residual is constructed as:

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

where $\hat{\tau}$ and $\hat{\gamma}$ are the Tobit maximum likelihood estimators (gotten from the first stage) and λ is the inverse Mills ratio from the Tobit model estimation. Next, the generalized residuals are included in the yield estimation (Wooldridge 2008) which we estimate using the CRE.

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 and thus excluded from (Z_1). The excludable instrument used in this analysis is the distance of each household to the local government of origin of the state governor[15]. 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).

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[15] 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.

In Nigeria, anecdotal evidence suggests that politicians patronize 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 article 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, the flow of diverted fertilizer across space implies that distance from key locations where governors may support access to subsidized fertilizer may also similarly affect access to commercial fertilizer. 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 and local government characteristics that could be potentially correlated with the distance variable (such as level of infrastructure, proximity to markets or towns and productivity) and affect rice yields[16]. Consequently, this variable is considered an appropriate instrument for the CFA conditional on controlling for these other factors (Wooldridge, 2015). In the empirical estimation, the instrument, distance from a households residence to the local government area (LGA) or origin of the state governor is used in the Tobit models in stage 1 and then is excluded from our estimation of the yield response function.[17] 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), Kamara et al (2011), Ekeleme et al (2010) and Witt et al (1999) to use a linear

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[16] To confirm that the validity of the instrument is not undermined by the presence of unobserved factors like lga wealth or productivity that might be correlated with the production of candidates likely to gain political office, we run a robustness check with the lga level asset wealth included and the study results are maintained. We also run specifications with lga dummies included and the study results are maintained though we lose the coefficients on variables that don't vary across lgas over time .

[17] There is some variation in the distance variable over time as there was a change in governors (and lga of origin) in some of the Nigerian states between the two survey rounds.

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. While a linear specification appears to be reasonable for our data, we recognize that there are limitations of this specification. If the true yield function is largely concave then the average response to nitrogen (APP) will exceed the marginal response to nitrogen (MPP) and δ will be an upward bias of marginal physical product[18].

With only about 330 households, we carefully select control variables to control for important factors and minimize 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 [19].We follow the literature in our selection of variables expected to affect rice yields. One additional feature of this study is the availability of some 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 level is less likely to be subject to specific individual farmer cropping choices, it is also likely to vary significantly over space. Thus, we consider this to be another proxy for general geographical variation that could affect fertilizer use and yields.

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[18] Given that our study results show that the marginal response to nitrogen is very low, this upward bias would only further strengthen the study argument that profitability is dampened by the low yield response to applied nitrogen.

[19] 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.

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. This data provided by the LSMS-ISA dataset comes from the National Oceanic and Atmospheric Administrations (NOAA) climate prediction center and available at a resolution of 0.1 dd. Data on labor use in agriculture is not available in the dataset for the first round. Consequently, household adult equivalency units were used as a proxy for available labor[20]. We 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[21]. We 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 (over 70% of the plots) versus those engaged in intercropping[22]. 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. Results:

Production function estimates

With the CFA, we first estimate the factors that determine the demand for nitrogen (our endogenous variable of interest) using a Tobit model. As mentioned earlier, the Tobit model specification accounts for the corner solution nature of inorganic fertilizer input use. Table 2 presents the Tobit results. It shows that farmers in closer 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.

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[20] 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

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

[22] Almost 20% of these are with one other crop and another 10% with 3 or more crops. The main other crops grown on these rice plots are other cereals (e.g. maize and sorghum) or leguminous crops (e.g. beans and cowpea).

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 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; Ezigbo, 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 3 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 reveal the endogeneity of the nitrogen variable but also correct for it (Rivers and Vuong, 1988; Smith and Blundel, 1986; Vella, 1993).

Next, the MPPs were estimated by taking the derivative of the production function with respect to applied nitrogen. 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 MPPS and APPs at the field level using the coefficients from our production function. The average marginal effect of applied nitrogen is about 8.9 and the MPP for farmers in this farming system range between about 3 and 15. This means that an additional kilogram per hectare of applied nitrogen increases rice yields per hectare by about 8.9 kilograms, all other things being held constant. Though similar, the average MPP is higher than the average APP, indicating increasing returns to scale. At the levels of fertilizer use in this sample this is surprising, a likely reflection of significant variation in plot level MPPs (see Table 4). We confirm that the share of rice plots for which the estimated marginal product is greater than the average product is a minority, at about 10%.

<<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

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in South West Nigeria. Consequently, our results tend to correspond with the general conclusion of these studies indicating that the yield response to fertilizer application in Nigeria is quite low for many rice farmers.

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:

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

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

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

Our basic analysis compares the profitability of nitrogen application at the plot level based on the expected MVCRs to observed nitrogen application to see if observed use patterns are in line with that which expected profitability would indicate. Following Xu (2008) and Sheahan et. al. (2014), the price of nitrogen used for this article is a simple average of the market price of the nitrogen components of Urea and NPK converted to a one kilogram equivalent. The market price is the amount paid for fertilizer divided by the quantity of fertilizer purchased by farmers who purchased fertilizer and the average price paid in the community was used for all households.

Fertilizer acquisition cost

Input acquisition in rural areas that are sometimes remote and with poor rural infrastructure and limited input supplier presence typically involves significant transactions cost for farmers (Winter-Nelson and Temu, 2005; Morris et al., 2007; de Janvry et al., 1991; Key et al.,2000). To account for the role high transportation costs play in the profitability of nitrogen application, we consider both the acquisition cost and the market price of nitrogen (Sheahan et al. 2013; Liverpool-Tasie et al., 2015a). As in these studies, 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. We add the total cost of securing a bag of fertilizer to the market price per kilogram. We agree with their rationale that the cost of moving fertilizer between two points is not likely to differ for 10kg, 50kg or 100kg in rural Nigeria if farmers are using a motorcycle or minibus (the main modes of transport in our sample). Payments are often made by trip, irrespective of quantity given the kinds of quantities we are considering here. One can argue that this might not be appropriate for some higher levels, if farmers were using a large truck to transport large amounts of fertilizer and thus enjoying economies of scale.

Majority of the rice farmers in our sample purchased their fertilizer from a market with just over 10% purchasing from friends or relatives. Over 85% of respondents who purchased fertilizer used a motorcycle or minibus to transport the input. The average cost faced by farmers purchasing fertilizer from the local market was about N460 and this was not too different from the transportation costs reported by those purchasing from friends or relatives (N450) indicating that these people might either not be resident in the farmer's village or that the farmer still had to bear the transportation cost to the market even where purchased from friends or relatives. These figures are similar to the transportation costs found by Liverpool-Tasie et al., 2015a who used this same dataset for a similar study on maize.

Generally, transportation costs to acquire fertilizer are very high in Nigeria. Liverpool-Tasie et al (2015a) found that about 70% of the total acquisition cost for 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)[23].

Output price:

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 (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[24]. 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[25].

Risk preferences

We consider how the profitability of nitrogen application (when farmers risk preferences are taken into consideration) varies across various policy scenarios. Liverpool-Tasie et al (2015a) find farmer behavior in rural Nigeria to be consistent with the implications of risk aversion. To account for risk preferences (since no data on risk attitudes was collected in the dataset) we follow the recent literature on fertilizer profitability for maize to incorporate a risk premium to account for the fact that a MVCR greater than 1 is likely to be necessary for risk averse farmers to be willing to use an input. A premium of 1 (thus an MVCR threshold of 2) has often been used (instead of MVCR threshold of 1) to account for risk preferences and other implications of input use such as higher labor demand, transportation and other transactions costs (Xu et al., 2009;

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[23] In our sample, farmers are on average about 70km away from the market and about 18km away from the nearest road. These distances are similar to those of Liverpool-Tasie et al (2015a) and based on gps coordinates of smallholder locations available in the LSMS-SA data and not from farmer responses. For full definition and source of the distance variables see Liverpool-Tasie et al. (2015a).

[24] Though very few households sold rice during the post planting season, the average selling price for rice sellers between post planting and post-harvest is not too different; about 5% in round1 and 10% in round 2. During the post-harvest period, about 60% of households sold some rice in each survey year.

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

Sauer and Tchale, 2009; Bationo et al., 1992; Sheahan et al., 2013; Kelly et al., 2005 Anderson et al., 1977) [26]. Since this article explicitly accounts for transportation costs in our analysis, a threshold value of 2 is likely too high though we recognize that a threshold value higher than 1 is likely necessary to capture farmers risk preferences (Burke, 2014). We follow Burke (2014) to consider 1.5 rather than 2 as a more reasonable threshold, but generally focus our discussion on how the distribution of MVCRs changes across various policy scenarios rather than on one particular threshold.

Fertilizer profitability on rice plots

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 both years, it is only profitable for about 20% of all rice plots when a MVCR threshold of 1.5 is used to account for risk preferences (Figure 1). This is not too surprising given the low MPP values for applied nitrogen and the high transportation cost associated with fertilizer use in rural Nigeria. Even when risk neutrality is assumed, applied nitrogen is profitable for less than half of the rice farmers. Consequently, we explore how the profitability of nitrogen application is likely to change under various policy scenarios. We specifically consider the effect of variations in the price of rice, transportation costs, fertilizer subsidies (a key policy used by Nigeria and many other countries in SSA as a response to the rhetoric that fertilizer use is too low because farmers cannot afford it) and yield response values on the profitability of fertilizer use.

The effect of rice prices on the profitability of nitrogen application

The output price is key for any profitability analysis. Though nitrogen application was only profitable for about 18% of rice plots in 2010, this number is slightly higher in 2012 at 23%. This 27% difference in the percentage of plots on which nitrogen application is profitable may be

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[26] 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. Rice bran is a residue from rice production that can be used, for example, as flooring for poultry farmers. It should be noted that rice bran (crop 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.

partly driven by the increase in the price of rice over the two years.[27] 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 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.

We find significant variation between the selling prices reported by farmers (who sold some rice) and the retail prices in the community (gotten from a community level survey conducted each survey round). 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 5 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 about 200% when the selling price is considered versus the community retail price. We ran various simulations to see how the profitability of fertilizer use would change if the community prices were what farmers received. These simulations recalculate the marginal value cost ratios for each plot, holding all other factors constant but changing the price of rice from the community retail price to the different possible retail prices in the community. 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 23% to about 75% for risk averse farmers maximizing expected profit (Figure 2).

<< Table 5 goes approximately here>>

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

Finally, national policies targeted at rice play a particularly important role in Nigeria. In response to the 2008 cereal price hikes, The Nigerian government has introduced several policies to support the domestic industry and increase local rice production. Among several programs, the Nigerian government restricts the quantity of rice imported. It uses various strategies including exorbitant tariffs on milled rice, often beyond 100%. The extent to which these policies affect local prices is an important question. While price transmission might not be complete, the LSMS data indicate that imported rice fetches a premium in rural communities. This likely reflects significant differences between local and imported rice (type and quality differences) which prevent local rice from being a perfect substitute in consumption for imported rice. This presents another opportunity (whose cost implications must be studied separately) for increasing the output price received by farmers and the consequent profitability of fertilizer use (Figure 2). This analysis demonstrates the importance of the price of rice for the profitability of nitrogen application in Nigeria.

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

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. Again the simulations involve recalculating the MVCRs for each plot, holding all other factors constant except the transportation cost which we vary. Transportation costs in rural areas are high for various reasons, including poor road quality and distance. Policy options will differ depending on the reason of focus. While road quality improvements involve significant capital costs, there are various options to reduce the distance farmers have to cover to secure inputs (e.g. supporting input dealers presence in rural communities) which have very different cost implications. We find that reducing the transportation costs associated with securing fertilizer by 50% more than doubles the percentage of plots on which nitrogen application would be profitable in the C-RCFS; from 18% to 42% in 2010 and from 23% to 52% in 2012 (Table 6, panel 1). A further reduction of transportation costs by 75% would just about triple the percentage of rice plots on which nitrogen application would be profitable in both years. 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[28]. 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[29].

The effect of fertilizer subsidies on the profitability of nitrogen application

Subsidizing fertilizer is a longstanding key component of Nigeria's agricultural support programs, often accounting for more than 30% of total federal government spending on agriculture (Mogues et al., 2008). Two key intentions of this policy are to improve the affordability of the input and increase fertilizer use to increase productivity. These goals are achievable if indeed farmers with high marginal productivity of fertilizer receive the subsidy. While details of the subsidy program vary over time (the previous scheme had a Federal government subsidy of 25% with states often providing additional support beyond the 25% for their farmers), the latest government program provides farmers with a 50% subsidy on two bags of fertilizer redeemable at private input dealers. 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.

Given the importance of fertilizer subsidies in Nigeria, we now consider the effect of reducing input prices with a fertilizer subsidy. We simulate the likely effect of receiving subsidized fertilizer on the profitability of nitrogen application for rice farmers using the 25% to 50% that is associated with recent government subsidy programs in Nigeria. Our dataset does not have any direct information about whether farmers received some subsidized fertilizer or not. For the simulations, we use a farmer's positive response to purchasing fertilizer from government as a proxy for participating in the government program as the Nigerian government is not typically involved in the sale of fertilizer. Only about 4% of respondents responded positively. We restrict the sample to those not using subsidized fertilizer but use the prevailing market price earlier

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[28] 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 6

[29] It is possible that even if fertilizer was available in the village a farmers might need to bear additional transport costs to move fertilizer from the village to the farm. The median distance of farmer homes from their farms is about 0.5 km in our sample and thus not likely to be an issue given that it is much lower than the distance covered when going to markets as shown in Liverpool-Tasie et al. (2015a).

defined as the base price. Then we run simulations with various levels of subsidy applied on this base price.

Table 6 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 25% subsidy, this would have increased the number of plots on which nitrogen application was profitable by about 30% from 18% to 24% in C-RCFS in 2010 and from 23% to 37% in 2012[30]. If a 50% subsidy was provided for all rice farmers, this would further increase the proportion of plots on which nitrogen application was profitable to 34% and 40% for 2010 and 2012 respectively. While these are significant effects, since only a small fraction of farmers typically receive subsidized fertilizer, the true profitability effect will be much lower than is depicted in Table 6 (panel 3)[31].

Figure 3 displays the Cumulative Distribution Function (CDF) of the MVCRs of rice farmers under different policy scenarios. The CDF under the 50% price subsidy first order stochastically dominates the distribution under the base scenario and a 25% subsidy while the CDF under the 25% subsidy scenario FOSDs the base scenario. However, when compared to the CDFs when various transportation policy effects are considered, it appears that reducing the transportation costs farmers face to secure fertilizer will have a larger effect on the profitability of fertilizer use than using fertilizer subsidies. This might be partially capturing the low MPP of applied nitrogen in rice production, which reduces the productivity effect of the subsidy. However, since transportation costs are such a high portion of the total acquisition cost for fertilizer, it is not surprising that 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 closer to farmers) 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 6 goes approximately here>>

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[30] 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

[31] Takeshima et al. (2013) demonstrate that less than 20% of farmers actually received subsidized fertilizer in Nigeria

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 MPP 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 6 (panel 2) 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 18% to 53% in 2010 and from 23% to 64% in 2012. If the MPP was higher at 25kg the application of nitrogen would be profitable for about 80% of rice plots, even at the current high acquisition costs of fertilizer. While the range of MPP values in our sample of rice farmers is between 3 and 15, response rates of 25 and higher are feasible based on field trials and studies in West Africa (Haefele and Wopereis, 2005).

Figure 3 clearly demonstrates that the distribution of MVCRs with a higher yield response of 15 exhibits First Order Stochastic Dominance (FOSD) over the base scenario and the distribution with a MPP of 25 first order stochastically dominates the base situation as well as situations with MPPs lower than 25. These results indicate the importance of the yield response to nitrogen application in the profitability of fertilizer use. This is a factor not often highlighted in the literature on fertilizer use generally, but more specifically that on fertilizer subsidies. Given the high cost of many of these subsidy programs, the importance of factors such as soil quality and management practices (e.g. timing of application and use of complementary inputs) on the productivity effects of fertilizer use are key factors to address to raise the yield response rates and consequently maximize the benefits of the program.

Figure 3 goes approximately here >>

Fertilizer profitability and observed farmer behaviour

Finally, we compare actual observed fertilizer use on rice plots in Nigeria with expected profit maximizing behavior. We use the estimates from the production function to determine if it is profitable for a farmer to use fertilizer or not and if a farmer should be expanding nitrogen

application. We consider a MVCR>=1 as an indication that a risk neutral farmer would gain from using fertilizer. A risk averse farmer would require a MVCR threshold greater than 1 to make it profitable to use fertilizer. We find that nitrogen is applied on over 60% of rice plots and the mean application rate is about 60kg per hectare (Table 7). The mean application rates are significantly higher among farmers for which the MVCR is greater than 1 compared to those for which it is not profitable (based on expected profit maximization) but on which fertilizer is being used. This mean difference is statistically significant at 5% or below. Furthermore, among farmers who are currently not applying any nitrogen on their rice plots, there are no plots on which fertilizer application would be profitable (Table 7). This result remains consistent irrespective of the profitability threshold (MVCR value considered necessary to indicate profitability) used. On the contrary, it appears that there are plots on which fertilizer use would not be considered profitable but on which fertilizer is being applied. This is consistent with Liverpool-Tasie et al. (2015a) who explain that this might be due to the fact that fertilizer use is also driven by other household and location specific factors which cause the shadow price of rice to be much higher than the observed market prices.

<< Table 7 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 of nitrogen application when estimating a rice production function. We find evidence that 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 also significantly reduce the profitability of fertilizer use.

Reducing transportation costs could more than triple the percentage of plots for which fertilizer use is profitable for rice farmers in the main cereal-root crop farming system. Linking farmers to input suppliers and making the product more available in rural communities 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 price is another key issue in the profitability of fertilizer use. Selling prices for local rice are extremely low in rural Nigeria and this 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 such as fertilizer and seed and to better 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 and improving the fraction of the retail price of rice captured by farmer, addressing the low marginal productivity of applied nitrogen is key. 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). It also indicates the need for further studies on the soil organic matter and other micronutrient availability for cereal farmers (Marenya and Barrett (2009); Snapp et al., 2014). There is likely also a significant role for extension and other innovatively structured mechanisms to disseminate agronomic best practices to rural farmers

Generally, this article confirms that fertilizer use which is clearly evident in rice production in Nigeria can be profitable[32]. However, at current input and output prices, this remains a reality 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 over 60% of rice plots use fertilizer. Nitrogen application among rice farmers

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[32] 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.

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.   While this article only focusses on rice, it confirms some of the findings in Liverpool-Tasie et al (2015a) for maize and raises issues that are likely to affect fertilizer use for other   crops[33].

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[33] Though capturing the main rice growing areas, this article 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 (1/0)	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
Male (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 (0/1)	19.182	0.405
Two other crop planted (0/1)	51.492*	0.056
Three or more other crop planted (1/0)	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 (mm)	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 (0/1)	1.111	0.971
moderate/sever challenges with soil nutrient retention capacity (0/1)	0.073	0.998
2012	-45.370	0.324
Regional dummies included	YES	
Mean of time varying decision variables included	YES	
Number of households	323	
Joint significance of regressors (p>chi2)	0.000	

*, ** and *** are significant at 10%,5%and 1% 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(0/1)	170.725	0.635	490.498	0.505	267.961	0.753
Irrigation (0/1)	-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
Male (0/1)	25.062	0.976	111.891	0.891	105.142	0.885
Age (years)	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 (1/0)	-933.141**	0.016	-78.342	0.918	-322.906	0.743
Two other crop planted (1/0)	-785.312	0.152	409.363	0.659	161.590	0.884
Three or more other crop planted (1/0)	-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
Other controls included+					YES	
CRE controls (mean of all time varying variables) included	NO		YES		YES	
Residual included in production function			NO		YES	
Generalized residual					-13.272	0.898
Generalized residual squared					403.437**	0.038
Number of households	323		323		323	
Adjusted R squared	0.436		0.462		0.524	

*, ** and *** are significant at 10%, 5% and 1% respectively. + is significant at 15% or less. + This regression also includes all explanatory variables included in the first stage regressions (except the distance to the LGA of the governor)

Table 4: MPPs and APPs of applied nitrogen

	MPP	APP
2010	8.92	8.67
2012	8.96	8.75

Source: Authors estimations from the LSMS-ISA data. These results are gotten from the results of the production function

Table 5: Price ratios across rural communities	**2010**	**2012**
Selling price of rice/ Nitrogen	0.26	0.27
Community retail price of local rice/ Nitrogen	0.78	0.81
Community retail price for imported rice/ Nitrogen	1.08	0.99

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 6 The proportion of rice plots for which fertilizer use is profitable for a risk averse farmer (MVCR>1.5) under various policy scenarios

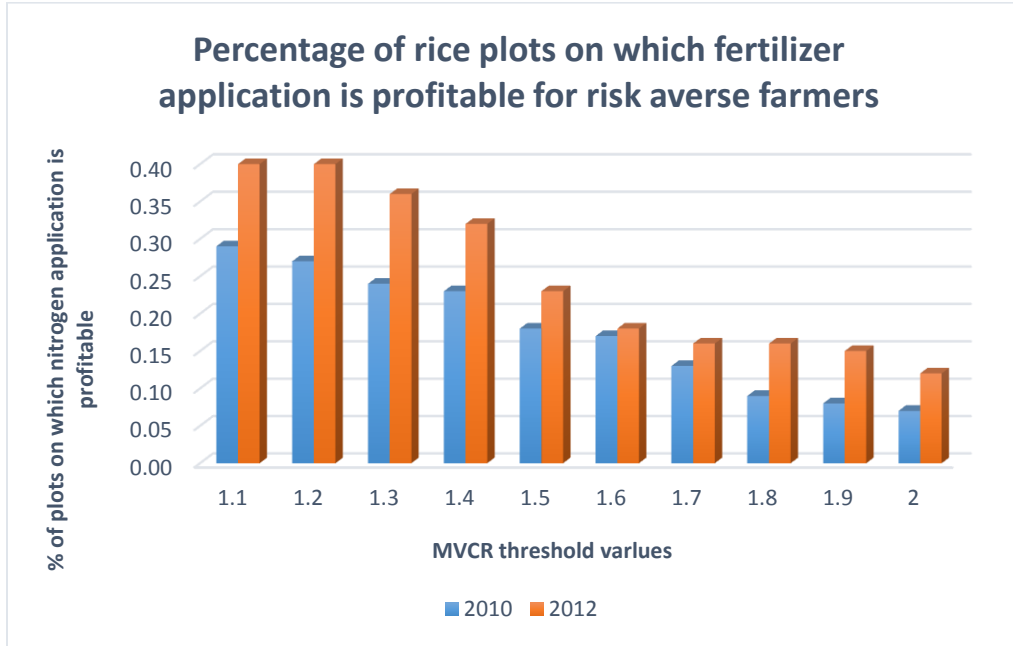|	Full acquisition cost	Transportation cost reduced by 50%	Transportation costs reduced by 75%	No transport cost-Fertilizer available in the village
2010	0.18	0.42	0.54	0.68
2012	0.23	0.52	0.63	0.75
	Current MPP at 8.9	MPP of 15	MPP of 20	MPP of 25
2010	0.18	0.53	0.72	0.79
2012	0.23	0.64	0.76	0.83
	Full price	25% subsidy on fertilizer price	50% subsidy on fertilizer price	
2010	0.18	0.24	0.34	
2012	0.23	0.37	0.40	

These results are gotten from a simulation of fertilizer profitability with different transportation costs, subsidy rates for the price of fertilizer and yield response levels.

Table 7: A comparison of actual and expected profit maximizing nitrogen application behavior in Nigeria

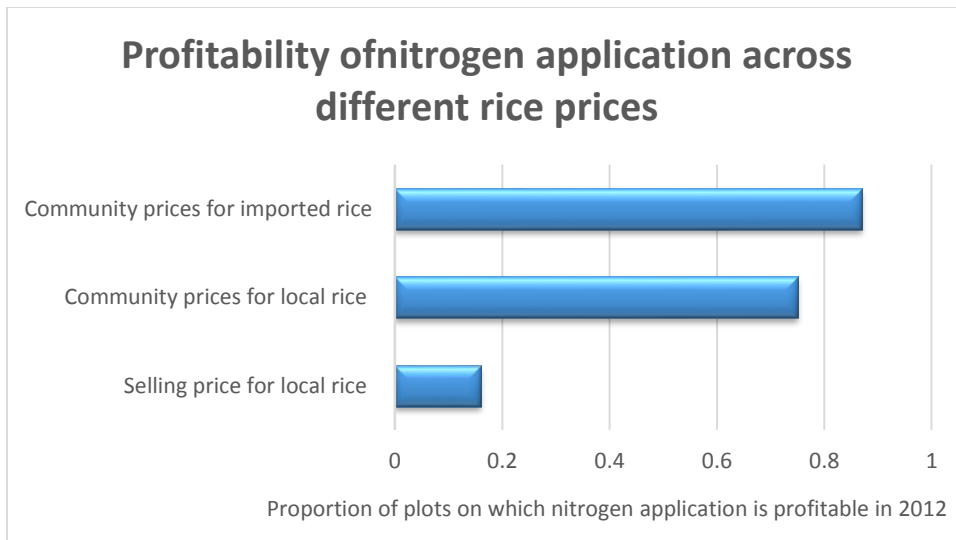|	Mean Nitrogen application rate on rice plots (kg/ha)	Mean Nitrogen application rate on rice plots for which nitrogen application is profitable (kg/ha) (MVCR>1) +	Mean Nitrogen application rate on rice plots for which nitrogen application is not profitable (kg/ha) MVCR<1)	Test of difference in mean application rates between MVCR>1 and MVCR<1	Percentage of plots not applying nitrogen	Percentage of plots not applying nitrogen for which it would be profitable (MVCR>=2++)
2010	62	99	44	***	36%	0%
2012	59	77	39	***	39%	0%

Source: Authors estimations from the LSMS-ISA data. + We use the conservative threshold since nitrogen application rates are higher, on average when a higher threshold of MVCR>2 is used. ++As expected if there are no plots not applying nitrogen for which it would be possible at a threshold of 2, this remains when risk neutrality is assumed as well as when a lower threshold is used to account for risk preferences.
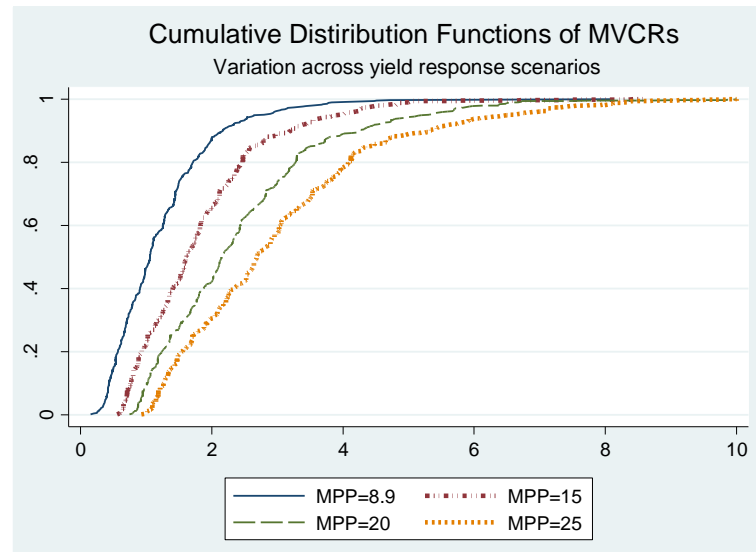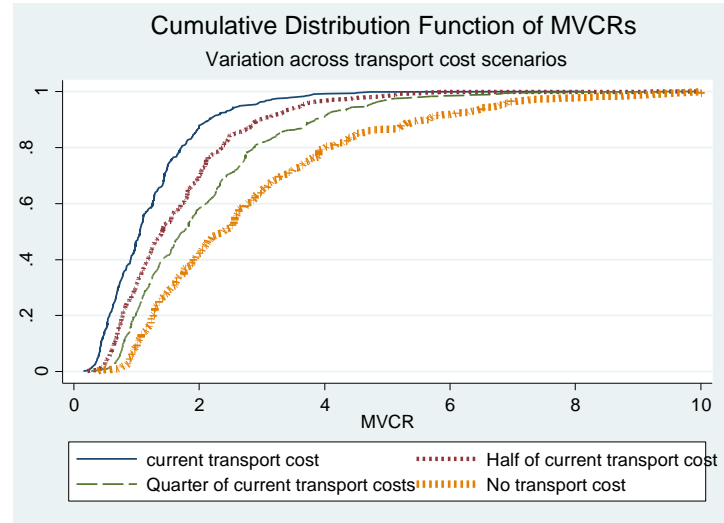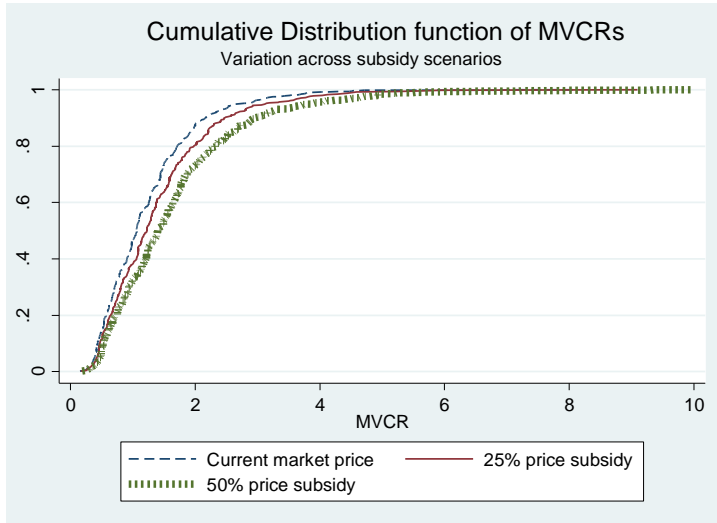
Figure 1:

Percentage of rice plots on which fertilizer application is profitable for risk averse farmers

Source: Generated by authors from the LSMS-ISA data and based on production function estimates

Figure 2:

Profitability ofnitrogen application across different rice prices

Source: Authors estimations from the LSMS-ISA data

Figure 3.

Source: Authors estimations from the LSMS-ISA data