The determinants of adoption of commercially-priced inorganic fertilizer for use on maize in Tanzania

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This paper uses panel data of smallholder farm households from Tanzania to empirically assess the determinants of adoption of commercially-priced inorganic fertilizer on maize by smallholder farmers in Tanzania. The results suggest that continuation of the large-scale fertilizer subsidy program NAIVS would only have a very small effect on improving the probability of smallholder use of commercially-priced fertilizer on maize. By contrast, policies to improve expected maize prices and reduce fertilizer costs as well as increasing smallholder access to extension would have the largest effect in achieving this outcome. This implies firstly that maize export bans (and/or temporary prohibition of obtaining an export permit) clearly have a significant negative effect on expected maize prices and thus the probability of fertilizer use on maize. Secondly, policies and investments to reduce the cost of fertilizer faced by farmers can increase the probability of fertilizer use on maize.

Keywords: Africa, fertilizer, smallholder agriculture

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ACRONYMS

AMIS	Agricultural Market Information System
BMGF	Bill & Melinda Gates Foundation
DAP	Di-Ammonium Phosphate
GDP	Gross Domestic Product
GISAIA	Guiding Investments in Sustainable Agricultural Intensification in Africa
GOT	Government of Tanzania
MAFL	Ministry of Agriculture, Fisheries, and Livestock
MIT	Ministry of Industry and Trade
MSU	Michigan State University
NAIVS	National Agricultural Input Voucher Scheme
NPS	National Panel Survey

1. INTRODUCTION

While Tanzania has enjoyed strong growth in GDP per capita since 2000 (approximately 7% per year), until 2007, this growth had led to neither substantial reductions in rural poverty nor significant improvements in household nutritional status (World Bank, 2015). While basic needs poverty declined from 34.4 percent to 28.2 percent between 2007 and 2012 (and extreme poverty declined from 11.7 percent to 9.7 percent), a large share of the population remains right above or below the poverty line, which implies that small changes in the cost of living can result in many households transitioning either into or out of poverty (ibid, 2015). Rural areas account for over 70 percent of Tanzania's population, 80 percent of the poor and the extreme poor in Tanzania live in rural areas, and more than half of the rural poor depend upon subsistence agriculture for their livelihoods (ibid, 2015). As has been recognized by donors and African governments alike in recent years, one of the keys to reducing rural poverty and improving the nutritional status of rural households in Tanzania will be to achieve wide-spread improvements in food crop productivity among smallholder farmers. Prior to the international food price crisis of 2007/08, maize yields in Tanzania remained low, averaging between 800-900 tons/ha nation-wide, despite Tanzania's favorable agro-ecological potential (NBS, 2004)[1]. Subsequently, maize production stagnated during the 2000s and did not keep pace with population growth (World Bank, 2009). While there are likely to be a range of factors which contribute to low maize yields in Tanzania, an obvious constraint is the fact that as of 2007/08 (NBS, 2008), few smallholders outside of the Southern Highlands region used inorganic fertilizer on maize or improved maize seed.

In 2008/09, with financial and technical support from the World Bank, the GoT dramatically scaled up their existing pilot targeted agricultural input voucher scheme – thereafter called the National Agricultural Input Voucher Scheme (NAIVS). NAIVS had two main goals: (1) to improve farmer access to inorganic fertilizer for use on maize/rice and improved maize/rice seed; (2) to provide a rapid, sustained and predictable increase in smallholder farmers' effective demand for inorganic fertilizer and improved maize/rice seed so as to promote longer-term investment by the private sector fertilizer and seed supply chains (World Bank, 2009). A third and longer-term goal of NAIVS was that by improving both physical access to fertilizer for smallholders and reducing the financial risk involved for both smallholders and the supply chain suppliers, this would provide a relatively low-risk learning opportunity and experience for all actors in the supply chain for fertilizer and improved seed use in maize and rice production. Ideally, this lower-risk 'experimentation period' would lead to an increase in smallholder demand for commercially priced fertilizer and improved seed, and an increase in supply chain actor investments in physical infrastructure, human capital, and exchange relationships so as to 'jump-start' the development of a spatially wider market-driven agricultural input distribution system.

[1] Average maize yields prior to the phasing out of fertilizer subsidies were approximately 1.2 tons/ha, though they dropped considerably in 1996-1998, and remained stagnant through 2003/04 (NBS, 2004).

In this paper, we use household-level data from the National Panel Survey (NPS) panel household surveys, which were implemented during the NAIVS period, to assess the determinants of farmer adoption of commercial inorganic fertilizer on maize. In particular, we assess the role of relative prices of fertilizer and maize as compared with other factors such as physical access to fertilizer retailers and ability to self-finance the purchase of market-priced fertilizer.

The paper is organized as follows. Section 2 provides a brief review of recent trends in the fertilizer supply chain in Tanzania. Section 3 describes the data used for our analysis, and Section 4 presents the conceptual framework used to investigate the determinants of farmer adoption of market-priced fertilizer for use on maize. Section 5 describes our empirical models and estimation strategy, and Section 6 presents our results. Section 7 provides conclusions and policy implications.

2. Recent trends in the fertilizer supply chain in Tanzania

2.1 Return to subsidies in 2003

In 2003, the Government of Tanzania (GoT) recognized that fertilizer use on food crops was very low, and in response, they re-introduced direct fertilizer subsidies for the first time since phasing out input subsidies completely from 1991 to 1994. From 2003 to 2007, the GoT subsidized internal transport costs of a limited quantity of fertilizer. However, this program was not successful in inducing widespread increased use of fertilizer on food crops, largely because the design was unable to ensure that those who first received the subsidy (distributors and/or agro-dealers) would pass on the savings to farmers.

2.2 The National Agricultural Input Voucher Scheme (NAIVS)

Beginning in 2007/08, the GoT decided to pilot a targeted voucher input subsidy program in two districts. In that year, only 12.9% of smallholder maize growers applied market-priced inorganic fertilizer to maize, though this ranged from a low of 1.1% in the Lake zone to 21.1% in the Southern highlands and 42% in the South zone (Table 1). Likewise, use of improved maize seed (either OPVs or hybrids) was also low, as 18.4% of smallholder maize growers used it in 2007/08. Although the southern highlands produce much of the country's maize and is a high potential zone, only 17% of maize growers there used improved maize seed in 2007/08.

In 2008/09, the GoT, with support from the World Bank, rapidly scaled up their pilot targeted agricultural input voucher subsidy program, in response to the international food price crisis the year before. NAIVS was intended to both address a short-term challenge of high food insecurity in 2008/09 and the longer-term challenge of improving smallholder demand for and access to inorganic fertilizer and improved seed for maize production. Beginning that year, the program was called the National Agricultural Input Voucher Scheme (NAIVS). In 2008/09, NAIVS scaled-up to reach smallholders in 58 districts distributed across 11 Regions in 2008/09. From 2008/09 through 2012/13, approximately US$300 million was invested in providing more than 2.5 million smallholder farmers with a 50 percent subsidy on a one acre package of maize or rice seed, and chemical fertilizer (World Bank, 2014a).

Table 1. Smallholder use of subsidized and market-priced inorganic fertilizer on maize and use of improved maize seed, by year and zone

	--Among maize-growing households (HHs), main season --											
	% HHs that applied subsidized or market-priced inorganic fertilizer to maize				% HHs that applied market-priced inorganic fertilizer to maize				% HHs that used improved maize seed			
Zone	2007/08	2008/09	2010/11	2012/13	2007/08	2008/09	2010/11	2012/13	2007/08	2008/09	2010/11	2012/13
S.Highlands	21.1	34.9	46.1	39.4	21.1	32.9	29.5	29.7	17.0	11.2	12.0	12.1
Northern	13.1	19.4	21.2	22.4	13.1	19.3	11.9	15.9	36.5	38.8	37.5	38.8
Eastern	4.3	3.1	3.1	2.9	4.3	1.5	2.9	2.7	13.5	11.9	9.8	9.2
Central	1.2	5.9	5.4	10.4	1.2	7.6	5.7	9.0	12.1	9.4	12.9	7.7
Lake	1.1	1.6	1.1	1.1	1.1	1.6	1.2	0.3	21.1	16.9	12.3	18.4
Western	3.0	15.2	20.8	24.5	3.0	12.0	21.9	22.5	20.4	6.7	11.1	4.0
South	42.1	4.0	5.1	6.3	42.1	2.3	6.5	6.2	12.8	4.0	7.5	3.8
Total	12.9	15.6	20.1	19.0	12.9	14.2	14.5	15.0	18.4	14.3	14.2	14.8

Source: 2007/08 Agricultural Census; National Panel Survey for other years. Notes: Southern highlands = Ruvuma, Iringa (& Njombe), Mbeya, Sumbawanga; North = Arusha (& Manyara), Kilimanjaro; Eastern = Morogoro, Tanga, Pwani, DES; Central = Dodoma, Singida, Tabora; Lake = Shinyanga, Mwanza, Manyara; West = Kigoma, Kagera; South = Lindi, Mtwara.

While the percentage of households using any fertilizer (subsidized or market-priced) increased during the years of NAIVS (2008/09 to 2012/13), the percentage of households purchasing market-priced fertilizer for use on maize remained between 14 and 15% during our three panel survey years, and increased in only the Western and Southern zone (Table 1). Use of improved maize seed (commercial or subsidized) stayed constant during that time period (Table 1).

3. DATA

3.1 Household-level data

In this paper, we use household survey data from the National Panel Survey, which was implemented by the National Bureau of Statistics (NBS) and consists of a sub-sample of both urban and rural households from the 2005/06 Household Budget Survey. This sub-sample was first interviewed in 2010 and for rural households the survey asked retrospective questions regarding household-, crop- and plot-level information such as land access and use, crop production and marketing, input use, livestock production and sales, etc during the previous main and short seasons.

The sub-sample was then re-interviewed in 2011 (to cover the 2010/11 main and short seasons) and in 2013 (to cover the 2012/13 main and short seasons). On mainland Tanzania, the NPS managed to re-interview n=1,389 households (68%) of the original 2008/09 sample in the two subsequent waves; n=209 (8.9%) were not re-interviewed in any wave; n=393 (17.5%) were re-interviewed in the second but not third wave; and n=111 households (5.5%) were re-interviewed in the third wave but not the second.

3.2 Village-level data

Information on the nearest seller of improved maize seed is contained in the community-level survey implemented with each wave of NPS. Upon releasing each wave of the NPS data with the Tanzanian National Bureau of Statistics (NBS), the World Bank also provided a range of agro-ecological variables (elevation, cumulative rainfall of wettest quarter, etc) that were generated by matching the village coordinates to secondary geospatial data. We also use constituency-level data from the 2005 presidential election, which included the number of votes by constituency for the presidential winner (Kikwete) that year as well as those for the runner-up.

3.3 Regional monthly wholesale prices of maize

Monthly wholesale data on maize prices comes from the Agricultural Market Information System (AMIS) of the Ministry of Industry and Trade (MIT). This data is collected on a weekly basis for several key staple crops and livestock products, from 20 of markets across the country. There is at least one wholesaler market tracked by AMIS in 20 of the country's 22 regions.

4. CONCEPTUAL FRAMEWORK

To estimate the effect of various potential determinants on household adoption of commercially-priced inorganic fertilizer for use on maize, we use the agricultural household model first developed by Singh, Squire and Strauss (1986) to derive a fertilizer demand function for a representative farm household in Tanzania. We assume that a representative farm household in Tanzania maximizes utility within an environment characterized by a number of market failures for some of its products (primarily food) and for some of its factors (notably credit). This implies that household consumption decisions are not separable from decisions concerning optimal household input and output levels. Under these assumptions, the agricultural household maximizes expected utility subject to production function, cash, credit, and time constraints. The solution to this optimization problem yields a set of output supply and factor demand equations, each of which are a function of expected output prices, variable input prices, and quasi-fixed factors. The implication of non-separability is that these output supply and input demand functions also depend upon characteristics of household consumption decisions, such as household wealth/income or demographic characteristics ((Sadoulet and de Janvry 1995; de Janvry and Sadoulet 2006). Given that fertilizer subsidy programs re-emerged in Kenya in 2007/08, the household's demand for commercial fertilizer may also be affected by receipt of an input subsidy voucher, which requires an additional modification to the standard factor demand model as described below.

Given these assumptions, our factor demand model for fertilizer as derived from the constrained utility maximization model as described by Sadoulet and de Janvry (1995) can be expressed as follows:

(1) $\text{Prob}(\text{UseFert}_c) = f(\text{QFert}_s, P_f, P_o, T, C, A, Z)$

where Prob($UseFert_C$) represents the probability that the household uses (or not) commercially priced fertilizer on maize, $QFert_S$ is the quantity of subsidized fertilizer that the household obtains, P_f is the commercial price of fertilizer, and P_o is a vector of prices of maize and other crops (outputs) on which fertilizer is most frequently used by Tanzanian smallholders. T represents the fixed transaction costs of acquiring fertilizer, such as distance to the nearest motorable road or distance to the nearest fertilizer retailer, and C is a measure of credit access. A represents household fixed productive assets such as total landholding, and Z represents other household production and socio-demographic characteristics.

5. EMPIRICAL MODELS and ESTIMATION STRATEGY

5.1 Empirical model

From the conceptual model above, we estimate a commercial fertilizer input demand model following Ricker-Gilbert et al (2011) to determine how the receipt of subsidized fertilizer affects the quantity of commercial fertilizer demanded by the household:

$$(2) \qquad Prob(UseFert_{cit}) = \beta X_{it} + \delta QFert_{sit} + \varepsilon_{it}$$

$$(3) \qquad \varepsilon_{it} = c_i + \mu_{it}$$

$UseFert_{cit}$ refers to the farmer decision to use (or not use) commercially priced fertilizer on maize, made by farmer *i* in year *t.* $QFert_{sit}$, represents the quantity of subsidized fertilizer received by farmer *i* in year *t,* and β and δ are parameters to be estimated. The key parameters of interest in (2) are β.

The quantity of subsidized fertilizer received by a household may well be endogenous due to correlation between this variable and unobserved factors (*ibid*, 2011), an issue we address below in sections 5.4 and 5.5. X_{it} is a vector of controls that are typically included in a model of household commercial fertilizer demand, such as the village-level fertilizer price, expected crop output prices, measures of the fixed costs of acquiring commercial fertilizer (distance to nearest road; distance to nearest seed retailer), measures of output market access (distance from village to nearest market), agro-ecological potential (agro-ecological zone dummies, a soil nutrient retention dummy[2], expected main season rainfall[3], elevation, household productive assets (total landholding, number of family members age 15-59), household credit access[4] (proxied by total household farm asset value), and other household socio-demographic information, as described in Table 3.

The error term ε_{it} in (3) is a function of two components. The first component c_i represents unobserved time-constant household-level factors such as soil quality, farm management skill, and/or risk preferences that may be correlated with observable household-level determinants

[2] Binary soil group indicator is from spatial variables provided by the World Bank and matched to the spatial coordinates of each NPS village.
[3] Expected main season rainfall computed as a 9-year moving average of cumulative rainfall during the wettest quarter in the year, also generated by the World Bank.
[4] We do not include a direct measure for access to farm credit because the survey data show that there is virtually no farm credit available in Tanzania for purchasing fertilizer for use on maize.

of household commercial fertilizer demand. The second component μ_{it} represents unobserved time-varying shocks that may affect household demand for commercial fertilizer, such as adverse climatic or pest events, health shocks, etc.

5.2 Dependent and explanatory variables

The dependent variable in our analysis is the binary household decision to use (or not use) commercial fertilizer on maize. Because receipt of subsidized fertilizer could affect this decision, we include the quantity of subsidized fertilizer received (from any source) in year *t* as an explanatory variable.

Literature on technology adoption in developing countries offers various explanations for non-adoption of a technology such as inorganic fertilizer by farmers (Feder et al, 1985). Two of the more common explanations relevant to inorganic fertilizer use include lack of information about the returns to fertilizer use and/or lack of physical access to fertilizer itself. We thus include a measure that =1 if the household received an extension visit in that year or a previous year (since learning from an extension visit would not be expected to be 'lost' over time). We include one binary indicator for a government extension visit and a separate one for an NGO or farmer cooperative extension visit.[5]

We also include a binary variable that =1 if improved maize seed is sold in the village. We use this variable as a proxy for access to inorganic fertilizer as that was not observed in the NPS. We also include the log of household farm assets as a measure of wealth, given that liquidity can often be a constraint to technology adoption (ibid, 1985). Because inorganic fertilizer is sometimes paired with improved maize seed (especially hybrids), we include the village percentage of households using improved maize seed (computed not using the household in question, so as to minimize potential endogeneity of this variable).

The decision to use an input is also a function of variables commonly included in a factor demand function, namely the price of the input (fertilizer) and the prices of outputs (crops). The fertilizer price used in our model is the log of the price of urea reported in Tanzanian shillings per kilogram of fertilizer. This price is derived from survey respondent purchase prices per kg commercial fertilizer. For households that did not purchase urea fertilizer at the market price in a given year, we use the district median urea price per kilogram that year.[6]

Because maize prices at harvest are not known at planting, we assume that the output price on which a given farmer bases his/her decision regarding fertilizer use is the expected post-harvest price of that output, which itself is based on information available to the farmer at or before planting, such as prices observed by the farmer in previous years. However, our survey data did not collect recall data on farm-gate post-harvest prices in the years prior to each survey wave,

[5] We do not include extension visits by private sector (i.e. agro-dealers) as this may happen simultaneously with fertilizer purchase and thus be endogenous.

[6] We do not include the DAP price given the lack of household observations of DAP purchased at commercial prices.

and our survey waves are 3-4 years apart, thus data on farm-gate post-harvest crop prices in the years preceding each survey wave is not available. Given that the Ministry of Industry of Trade (MIT) collects wholesale prices throughout the year for maize, we develop a naïve price expectation for maize in year *t* which is the average real wholesale price from the nearest wholesale market during the post-harvest period of the previous year's main season harvest.[7] We compute the expected maize price as the average of the average monthly price for the four months following the main season maize harvest for each agro-ecological zone in the previous year.

We also include as a control variable the percentage of ward farmers who grow coffee or tobacco, as these crops typically give such farmers access to fertilizer via inter-linked credit. Although such fertilizer is intended for coffee/tobacco, leakage to food crops can occur. In addition, the generally high returns from coffee and tobacco make such households more likely to be able to afford fertilizer for use on a food crop like maize. Likewise, we use a separate variable that is the percentage of ward farmers that grow commercial horticultural crops (Irish potato, onion, tomato or carrot) that typically are grown with inorganic fertilizer, according to NPS crop and plot-level data.

Given that nearly all smallholder maize production in Tanzania is rainfed, we include a village-level measure of expected cumulative rainfall in the wettest quarter of the year[8]. Expected rainfall is computed as a 9-year moving average prior to each survey waves. We also use secondary geospatial data to create a dummy variable that =1 for villages that have 'moderate' or 'severe' soil nutrient retention problems, as well as village-level information on elevation.[9] Finally, we include binary indicators for the years represented by survey waves of 2010/11 and 2012/13 to control for the average effect of unobserved factors.

5.3 Modeling a Binary Dependent Variable

We model the binary dependent variable that =1 if a household purchased commercial fertilizer for use on maize using a probit estimator. To facilitate interpretation of the results from the non-linear models such as a probit, we compute the average partial effect (APE) for each explanatory variable. We compute APEs instead of the partial effect at the means of the explanatory variables as Wooldridge (2002) notes that this latter partial effect may not in fact be representative of the actual household population.

5.4 Controlling for Unobserved Time-Constant Heterogeneity c_i

If unobservable time-constant characteristics such as soil quality, farm management ability, or risk preferences are correlated with observable determinants of household commercial

[7] The nearest wholesale market is generally the regional capital, as MIT collects weekly wholesale price data from 22 of the country's 24 regional capitals on the country's staple grain, legume and root crops.

[8] Rainfall estimates are derived from the W.Bank (World Bank, 2010; W.Bank 2012; W.Bank, 2014), who used geospatial rainfall estimates that are based on data from satellites (such as on cloud cover and cloud top temperatures) and rain stations, which are combined to interpolate estimates of decadal (10-day period) rainfall, which can be matched to sample households/villages using global positioning system (GPS) coordinates.

[9] Generated using spatial coordinates of each village and secondary data on elevation (SRTM, 2000).

fertilizer demand (such as total land area owned, household wealth level, head's education level, etc) or the quantity of subsidized fertilizer received by the household, this can lead to biased coefficient estimates (i.e. termed omitted variable bias by Wooldridge (2002)). The household data set used in this paper is longitudinal, which offers the analytical advantage of enabling us to control for time-constant unobservable household characteristics (c_i). While the fixed effect (FE) estimator is usually the most practical way to control for these unobserved time-constant household characteristics, it is problematic for our purposes as the FE Probit estimators have been shown to be inconsistent (Wooldridge 2002).

We estimate the probit model in this paper with a Correlated Random Effects (CRE) (Mundlak 1978; Chamberlain 1984) estimator, which explicitly accounts for unobserved heterogeneity and its correlation with observables, while yielding a fixed-effects-like interpretation on the time-varying variables. In contrast to traditional random effects, the CRE estimator allows for correlation between unobserved heterogeneity (c_i) and the vector of explanatory variables across all time periods (X_{it}) by assuming that the correlation takes the form of: $c_i = \tau + \alpha X_{i\text{-}bar} + a_i$ where $X_{i\text{-}bar}$ is the time-average of X_{it}, with $t = 1, \ldots, T$; τ is a constant, and a_i is the error term with a normal distribution, $a_i \mid Xi \sim \text{Normal}(0, \sigma^2_a)$. We estimate a reduced form of the model in which τ is absorbed into the intercept term and $X_{i\text{-}bar}$ are added to the set of explanatory variables.

5.5 Controlling for Unobserved Shocks μ_{it}

While we use the CRE approach outlined above to control for time-constant unobserved household heterogeneity (c_i), our estimates of the partial effect of regressors on commercial fertilizer use could still be subject to endogeneity bias. This could occur if unobserved time-varying shocks are correlated with $QFert_s$ in equation (2), which in this case might arise if government officials and/or village leaders target fertilizer subsidy vouchers based in part on unobservable time-varying attributes of villages and/or households (Ricker-Gilbert et al, 2011). Following Ricker-Gilbert et al (2011), we test for correlation between time-varying factors and the quantity subsidized fertilizer using an adapted Control Function (CF) approach developed by Rivers and Vuong (1988) to control for a continuous endogenous explanatory variable, and by Vella (1993) to control for an endogenous variable that is also a corner solution.[10]

As with the 2SLS approach to instrumenting for an endogenous variable, the CF approach requires an instrumental variable (IV) that satisfy two criteria. First, the IV must have a significant effect on the endogenous variable (quantity of subsidized fertilizer received) used in the reduced form regression. Second, we must assume that our instruments are not correlated with the dependent variable of the structural equation (quantity of commercial fertilizer demanded), conditional on the other observable factors -- a maintained assumption that cannot be tested. We use a constituency-level electoral variable "Electoral threat" as an IV, which is defined as the ratio of the proportion of votes for the runner-up (in the 2005 presidential election) over the proportion of votes for the presidential winner (Chang, 2005). Because we are separately controlling for factors typically correlated with fertilizer demand

[10] See Ricker-Gilbert, Jayne, and Chirwa (2011) for a recent application of this adapted control function approach.

such as agro-ecological potential or wealth levels (in the set of controls X_{it}), as well as time-constant unobservable factors (thru the CRE time-average terms), there is little reason to suspect that our IV would be correlated with any remaining time-varying factors in the error term of commercial fertilizer demand as described by (2).

5.6 Panel Attrition

For our econometric analysis, although we are only using the latter two waves of the NPS panel for our econometric estimation of (2) above, this implies that we are using households that were interviewed in all three waves of NPS. If households that are not re-interviewed are a non-random sub-sample of the population, then using the re-interviewed households to estimate the means or partial effects of variables during one of the later panel time periods may result in biased estimates. To test for panel attrition bias, we follow the regression-based approach described in Wooldridge (2002) and define an attrition indicator variable that is equal to one if the household dropped out of the sample in either the second or third wave of the panel survey, and equal to zero otherwise. This binary variable is then included as an additional explanatory variable in our DH model (2), which is run using all household observations from the initial survey wave 2008/09.

For the following analysis, we use an unbalanced household sample of n=933 households that grew maize from the three survey waves (a total of n=2,637 observations). The results of our regression-based attrition test find that the binary indicator of attrition is insignificant in the probit regression (p=0.512). We thus proceed with descriptive and econometric analysis using sampling weights from 2008/09.

6. RESULTS

6.1 Econometric Analysis

6.1.1 Determinants of household receipt of subsidized fertilizer

Appendix Table 1 presents descriptive statistics of the variables used in our tobit and probit regressions. Table 2 presents results from a reduced form Tobit model of the quantity of subsidized fertilizer received by the household. The IV "constituency-level electoral threat" is significant at the 5% level (p= 0.023), lending credibility to its validity as an IV. The positive sign on this variable suggests that households in areas with greater electoral threat to the ruling party receive more subsidized fertilizer, holding other factors constant.

6.1.2 Test for endogeneity of household quantity of subsidized fertilizer received

As noted in Section 5.5 above, we use a control function approach to test for the potential endogeneity of the household quantity of subsidized fertilizer received. The first stage of this approach is to estimate a reduced form tobit regression for the household quantity of subsidized fertilizer received, including an IV 'constituency-level electoral threat'. We then add the endogenous variables and the residuals from the reduced form tobit into the probit of commercial fertilizer use on maize. We find that control function tobit residual is significant in the probit (p=0.023). However, as this variable is a generated regressor, we bootstrap its standard error to assess its significance and find it insignificant (p=0.028). Thus, we conclude that household quantity of subsidized fertilizer is exogenous, and we do not leave the control function residual in the probit.

Table 2. Reduced form Tobit regression of factors affecting household quantity of subsidized fertilizer obtained, 2008/09, 2010/11, 2012/13

	Tobit-CRE	
	Dep variable = HH quantity of subsidized fertilizer obtained	
Explanatory variable	APE	Pvalue
Year dummy (1=2011)	110.207	0.000
Year dummy (1=2013)	49.655	0.005
ln(Expected rainfall in wettest quarter (mm))	173.003	0.001
Elevation - meters above sea level	-0.009	0.625
1=soils with poor nutrient retention	23.836	0.096
distance to nearest market (km)	0.143	0.381
distance to nearest road (km)	-0.495	0.167
1=improved maize seed sold in village	48.608	0.000
% ward farmers that used improved maize seed	108.139	0.000
% ward farmers that grew coffee or tobacco	93.707	0.019
% ward farmers that grew cash horticulture crop	24.609	0.362
ln(real exp price of maize (Jul-Sep) / real price of urea)	-690.421	0.079
1=HH received GoT extension visit in this or prior year	30.543	0.034
1=HH received NGO/coop extension visit in this or prior year	69.681	0.001
ln(real farm equipment value)	6.057	0.159
Total landholding size (Ha)	0.850	0.477
Head's age (years)	0.814	0.150
Maximum education in the HH (years)	6.406	0.054
# of HH members age 15-64	5.676	0.610
1=HH head is single female	-8.788	0.819
Number of children age 0-15	-7.792	0.324
Number of HH members age 65 or above	-36.117	0.279
Constituency-level electoral threat	167.863	0.023
Number of observations	2,641	
Correlated random effects terms included	yes	
Psuedo R-squared	0.143	

Notes: Model includes binary indicators for agro-ecological zone (6 of 7), a squared term for head's age, and time averages terms for each of the time-varying regressors except for head's age. APE= Average Partial Effect. Population sampling weights from 2008/09 applied via Stata.

Table 3. Probit of household use of commercial fertilizer on maize, 2008/09, 2010/11, 2012/13

	Probit-CRE	
	Dep variable = 1 if HH purchased commercial fertilizer	
Explanatory variable	APE	Pvalue
Year dummy (1=2011)	-0.0330	0.0230
Year dummy (1=2013)	-0.0278	0.0630
ln(Expected rainfall in wettest quarter (mm))	0.1347	0.0120
Elevation - meters above sea level	0.0000	0.9750
1=soils with poor nutrient retention	-0.0130	0.4110
distance to nearest market (km)	0.0005	0.0000
distance to nearest road (km)	-0.0020	0.0000
1=improved maize seed sold in village	0.0371	0.0090
% ward farmers that used improved maize seed	0.1486	0.0000
% ward farmers that grew coffee or tobacco	0.1203	0.0200
% ward farmers that grew cash horticulture crop	0.1635	0.0000
ln(real exp price of maize (Jul-Sep) / real price of urea)	0.7712	0.0520
1=HH received GoT extension visit in this or prior year	0.0554	0.0070
1=HH received NGO/coop extension visit in this or prior year	0.1418	0.0000
HH qty of subsidized fertilizer received (kg)	0.0003	0.1310
ln(real farm equipment value)	0.0033	0.4580
Total landholding size (Ha)	-0.0010	0.3710
Head's age (years)	-0.0004	0.5050
Maximum education in the HH (years)	-0.0059	0.1380
# of HH members age 15-64	-0.0017	0.8680
1=HH head is single female	0.0109	0.7350
Number of children age 0-15	0.0194	0.0110
Number of HH members age 65 or above	-0.0165	0.5020
Number of observations	2,637	
Correlated random effects terms included	yes	
Psuedo R-squared	0.299	

Notes: Model includes binary indicators for agro-ecological zone (6 of 7), a squared term for head's age, and time averages terms for each of the time-varying regressors except for head's age. APE= Average Partial Effect. Population sampling weights from 2008/09 applied via Stata.

6.1.3 APE of typical factors known to affect household commercial fertilizer demand

Due to space limitations, the estimation results of our probit model do not include the APEs for zonal dummies (Table 3). However, the joint significance of these variable groups in the probit is quite strong (p=0.000). Our control for expected rainfall has the expected positive and significant effect on commercial fertilizer use on maize (Table 3). For example, a 10% increase in expected rainfall in the wettest quarter increases the probability of commercial fertilizer use on maize by 1.3%.

The price ratio of the expected real maize price over the real urea price has the expected positive sign, is significant (p=0.05) and has a relatively large effect on the probability of fertilizer use on maize. For example, a 10% increase in this price ratio increases the probability of commercial fertilizer use on maize by 7.7% (Table 3). This result has two main implications. The first is that maize export bans (and/or temporary prohibition of obtaining an export permit) clearly have a significant negative effect on expected maize prices and thus the probability of fertilizer use on maize. The second implication is that policies and investments to reduce the cost of fertilizer faced by farmers can increase the probability of fertilizer use on maize.

Second, physical proximity to agro-dealers is important but does not have as large an effect as might be expected. For example, where improved maize seed is sold in the village, the probability of fertilizer use on maize increases by 3.7% (Table 3). That said, we are not able to measure distance to nearest fertilizer retailer itself, thus we use the presence of a maize seed retailer in the village as a proxy for this.

Third, access to fertilizer via crops that receive fertilizer via interlinked credit (such as coffee, tobacco) or commercial horticultural crops (such as Irish potato, onion, tomato or carrot) increases the probability of fertilizer use on maize. For example, a 10% increase in the percentage of ward farmers growing coffee or tobacco increases the probability of fertilizer use on maize by 1.2%.[11] Likewise, a 10% increase in the percentage of ward farmers growing a commercialized horticultural crop increases the probability of fertilizer use on maize by 1.6%. While living in a ward with coffee/tobacco or commercialized horticultural crops is an important source of inorganic fertilizer for maize growers, only about 4% (9%) of maize growers live in a ward with coffee/tobacco (commercialized horticulture).

Fourth, receipt of a government extension visit this year or in a prior year increases the probability of commercial fertilizer use on maize by 5.5%. Receipt of an NGO or coop extension visit has an even larger effect on the probability of fertilizer use, increasing it by 14.1%. This suggests that extension can play a vital role in increasing farmer use of fertilizer on maize.

As expected, we also find a positive effect of the percentage of ward farmers that used improved maize seed on the probability of fertilizer use on maize. For example, a 10% increase in this percentage would increase the probability of fertilizer use on maize by 1.48%.

As in many other SSA countries, farm credit for agricultural inputs in rural Tanzania is rare in the absence of sufficient household collateral and/or interlinked credit via a cash crop out-grower scheme. Given this context, it is surprising that neither of our proxies for wealth (total farm size

[11] A one unit change in this explanatory variable represents the entire range of the variable from 0 to 1, and is thus not a marginal change. To compute a marginal change for this proportional variable, we multiply the marginal effect shown in Table 3 by a smaller percentage increase, such as 10%.

and the log of farm equipment value) have a significant positive effect on the probability of fertilizer use on maize.

We find that distance to nearest road has the expected negative effect on the probability of commercial fertilizer purchases, as this distance often represents a large portion of actual transportation costs to the nearest large-scale market (Table 3). For example, an additional 5 km to the nearest road decreases the probability of fertilizer use on maize by 1%. We unexpectedly find that the effect of distance to market is positive for quantities purchased. That said, distance to the nearest market does not appear to be as important for maize sales as might be assumed, as approximately 80% of smallholder maize sales in 2012/13 occurred in the village.

Recent research has found a small positive effect of subsidized fertilizer receipt on the probability of commercial fertilizer use on any crop in Tanzania (Mather and Minde, 2016). Here, we find that receipt of a kilogram of subsidized fertilizer increases the probability of commercial fertilizer purchase for use on maize by 0.03% (Table 3). This means that receipt of one fertilizer voucher (for 50kg of subsidized fertilizer) would increase the recipient household's probability of purchasing commercial fertilizer on maize by 1.5%. This variable may also be serving as a fertilizer access variable, because agro-dealers that target villages with subsidized fertilizer also sell commercial fertilizer there as well.

7. CONCLUSIONS

This paper uses descriptive and econometric analysis of panel household survey data to assess the determinants of smallholder farmer adoption of inorganic fertilizer for use on maize in Tanzania. There are six main findings.

First, although the percentage of smallholder maize growers using inorganic fertilizer increased from 2008/09 to 2012/13 during the roll-out of NAIVS (a large-scale fertilizer subsidy program in Tanzania), the percentage of smallholder maize growers using market-priced fertilizer remained relatively constant during this time period.

Second, the price ratio of the expected real maize price over the real urea price has a large positive and significant effect on the probability of fertilizer use on maize. For example, a 10% increase in this price ratio increases the probability of fertilizer use on maize by 7.7%. This result has two main implications. The first is that maize export bans (and/or temporary prohibition of obtaining an export permit) clearly have a significant negative effect on expected maize prices and thus the probability of fertilizer use on maize. For example, recent research has found that the implementation by the GoT of a maize export ban between July to December 2011 resulted in maize prices that on average were 8.7% lower across the country than they would have been in the absence of an export ban, and that maize prices in Songea would have been 31% higher in December 2011 without the ban that year (Baffes et al, 2015). Reducing the price of maize to price of fertilizer ratio has a negative effect on the probability of fertilizer use, thus export bans clearly undermine smallholder demand for fertilizer use on maize through their effect on farmers' expectations regarding future maize prices.

Although the GoT pledged in 2013 to stop using maize export bans, since then, potential exporters have had to obtain an export permit in order to export maize, and approval of such permits is sometimes refused. For example, sometimes an individual region will declare a maize export ban and refuse to approve export permits, or more recently, the Ministry of Agriculture Livestock and Fisheries (MALF) applied a temporary nation-wide ban on export permits in 2016. Thus, continuing grain price uncertainty caused by unpredictable export bans and/or unobtainable export permits may well be undermining the gains made during NAIVS in smallholder demand for commercial fertilizer for use in maize production. There is thus an urgent need for GoT to adopt predictable, transparent, rules-based trade and marketing policies to reduce the risk/uncertainty of farmer, trader, and wholesalers' expectations of future maize prices.

The second implication of this finding is that policies and investments to reduce the cost of fertilizer faced by farmers can increase the probability that they use market-priced inorganic fertilizer on maize. The most direct ways to reduce domestic costs of fertilizer would be increased investment in port facilities and rural roads as well as an increase in bulk purchasing.

Third, physical proximity to agro-dealers is important but does not have as large an effect as might be expected. For example, where improved maize seed is sold in the village, the probability of fertilizer use on maize increases by 3.7%. That said, we are not able to measure distance to nearest fertilizer retailer itself, thus the presence of a maize seed retailer in the village is a proxy for this.

Fourth, living in a ward with coffee/tobacco or commercialized horticultural crops (such as Irish potato, onion, tomato, or carrot) is an important source of inorganic fertilizer for some maize growers, given that these crops typically receive fertilizer via interlinked credit. For example, a 10% increase in the percentage of ward farmers growing coffee or tobacco increases the probability of fertilizer use on maize by 1.2%. Likewise, a 10% increase in the percentage of ward farmers growing a commercialized horticultural crop increases the probability of fertilizer use on maize by 1.6%. However, only about 4% (9%) of maize growers live in a ward with coffee/tobacco (commercialized horticulture).

Fifth, distance to nearest road has the expected negative effect on the probability of commercial fertilizer purchases, as this distance often represents a large portion of actual transportation costs to the nearest large-scale market. For example, an additional 5 km to the nearest road decreases the probability of fertilizer use on maize by 1%. This result also suggests that investment in rural roads can increase fertilizer use on maize.

Sixth, receipt of a government extension visit this year or in a prior year increases the probability of commercial fertilizer use on maize by 5.5%. Receipt of an NGO or coop extension visit has an even larger effect on the probability of fertilizer use, increasing it by 14.1%. This suggests that extension can play a vital role in increasing farmer use of fertilizer on maize.

In conclusion, the results suggest that continuation of NAIVS would only have a very small effect on improving the probability of smallholder use of commercially-priced fertilizer on maize. By contrast, policies to improve expected maize prices and reduce fertilizer costs as well as increasing smallholder access to extension would have the largest effect in achieving this outcome.

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Appendix Table 1. Descriptive Statistics of variables used in Tobit and Probit regressions

	2008/09		2010/11		2012/13	
Dependent variable	mean	SD	mean	SD	mean	SD
1=household used inorganic fertilizer on maize	0.1423	0.3495	0.1436	0.3509	0.1514	0.3587
Explanatory variables						
Southern Highlands (base zone)	0.2893	0.4537	0.3179	0.4659	0.3003	0.4587
Northern zone	0.1199	0.3251	0.1113	0.3147	0.1395	0.3467
Eastern zone	0.1687	0.3747	0.1752	0.3804	0.1678	0.3739
Central zone	0.1174	0.3220	0.1312	0.3378	0.1080	0.3106
Lake zone	0.1518	0.3590	0.1090	0.3118	0.1443	0.3516
Western zone	0.0770	0.2668	0.0732	0.2606	0.0757	0.2647
South zone	0.0758	0.2649	0.0822	0.2748	0.0644	0.2455
ln(Expected rainfall in wettest quarter (mm))	6.1773	0.2870	6.1820	0.2969	6.1629	0.3031
Elevation - meters above sea level	1075.6340	472.8777	1076.2290	488.8654	1103.6470	468.6379
1=soils with poor nutrient retention	0.4118	0.4924	0.4134	0.4927	0.4141	0.4929
distance to nearest market (km)	78.8861	51.7904	80.8202	51.4723	77.4989	52.3529
distance to nearest road (km)	20.2072	20.5402	20.9201	20.9078	20.1934	21.0964
1=improved maize seed sold in village	0.1192	0.3242	0.4412	0.4968	0.5340	0.4991
% ward farmers that used improved maize seed	0.1172	0.1627	0.1147	0.1668	0.1320	0.1920
% ward farmers that grew coffee or tobacco	0.0432	0.1276	0.0411	0.1239	0.0529	0.1444
% ward farmers that grew cash horticulture crop	0.0873	0.1962	0.0873	0.2031	0.0901	0.2126
ln(real exp price of maize (Jul-Sep) / real price of urea)	0.8137	0.0140	0.8262	0.0137	0.8307	0.0205
1=HH received GoT extension visit in this or prior year	0.1483	0.3556	0.2098	0.4074	0.2499	0.4332
1=HH received NGO/coop extension visit in this or prior ye	0.0405	0.1972	0.0579	0.2337	0.0795	0.2707
HH qty of subsidized fertilizer received (kg)	1.8935	15.5359	10.9804	35.1455	5.6121	23.8155
ln(real farm equipment value)	10.7555	1.5607	10.6065	2.1760	10.7933	2.0461
Total landholding size (Ha)	5.6166	6.6952	6.0902	7.0703	6.0020	8.3408
Head's age (years)	45.7386	8.8435	49.2278	15.6369	48.8852	10.9310
Maximum education in the HH (years)	6.9240	0.6828	7.2761	2.0672	7.2201	1.5533
# of HH members age 15-64	2.3851	1.2921	2.5437	1.4219	2.6518	1.4313
1=HH head is single female	0.1551	0.3622	0.1712	0.3769	0.1696	0.3755
Number of children age 0-15	2.4688	1.8432	2.5195	1.9084	2.5645	1.8952
Number of HH members age 65 or above	0.2562	0.5427	0.2967	0.5658	0.2578	0.5348
Constituency-level electoral threat	0.1063	0.1300	0.1024	0.1333	0.0976	0.1296
Number of observations	934		861		846	