Fertilizer subsidies and how targeting conditions crowding in/out: An assessment of smallholder fertilizer demand in Tanzania

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We use panel data of smallholder farm households from Tanzania to empirically assess a large-scale fertilizer subsidy program in Tanzania with respect to its ability to meet its stated targeting criteria and the effect of subsidy receipt on both smallholder commercial fertilizer demand and total fertilizer use. We find that the majority of subsidy recipients met the targeting criteria in practice in regards to area cultivated to maize and that few of them had used inorganic fertilizer on maize or rice in the previous five years. However, we also find that depending on the year, between 25 to 37% of households receiving a fertilizer voucher did not use it, implying that these households did not gain the experience using fertilizer on maize or rice as envisioned by NAIVS. We find that receipt of one kilogram of subsidized fertilizer has a small (0.11 kg) but significant positive effect on smallholder commercial fertilizer demand. This implies that NAIVS is the only large-scale fertilizer subsidy program in Sub-Saharan African during the 2008-2014 period that managed to avoid 'crowding-out' of smallholder commercial fertilizer demand at a national level, on average. When we adjust the effect of household receipt of subsidized fertilizer on total smallholder fertilizer use (given that 25 to 37% of subsidized fertilizer was not actually used by intended recipients) the adjusted effect of an extra kilogram of subsidized fertilizer on total fertilizer use in 2012/13 (2008/09) was 0.827 kg (0.697 kg).

Keywords: Africa, fertilizer subsidy, smallholder agriculture

JEL codes: Q12, Q18

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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
ISFM	Integrated Soil Fertility Management
MAFC	Ministry of Agriculture, Food Security, and Cooperatives
MIT	Ministry of Industry and Trade
MRP	Minjingu Rock Phosphate
MSU	Michigan State University
NAIVS	National Agricultural Input Voucher Scheme
NPS	National Panel Survey
SUA	Sokoine University of Agriculture

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).

The initiation of NAIVS in 2008/09 coincided with a resurgence of government-led fertilizer subsidy programs during this time period across a growing number of SSA countries including Ghana, Kenya, Malawi, Nigeria, Rwanda, and Zambia. The publically-stated goal of many of these programs is to induce higher levels of smallholder fertilizer use, which are assumed to lead to improvements in crop productivity and thus higher household incomes and improved food security. However, the degree to which an input subsidy program raises total smallholder fertilizer use depends on the extent to which receipt of subsidized fertilizer crowds-out (or crowds-in) the quantity of commercial fertilizer that a subsidy recipient smallholder

[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).

theoretically would have purchased at the market rate in the absence of a subsidy (Ricker-Gilbert, Jayne, and Chirwa 2011).[2]

In contrast to the government-led input subsidy programs of the pre-structural adjustment era in SSA, which typically took the form of state monopsonistic control of input distribution and a pan-territorial subsidized input price for all buyers, a critical feature of what Morris et al (2007) call 'smart' input subsidy programs is for them to be specifically designed to work within (and support the development of) the existing private sector input distribution system, thereby reducing the well-known inefficiencies of the previous state-led approaches. A key institutional design feature of what Morris et al (2007) call a 'smart' agricultural input subsidy programs is to limit the government's role in the program primarily to the distribution of vouchers that enable recipient households to acquire a specified quantity of fertilizer at a subsidized price from a local private input dealer. The use of vouchers within the existing private sector input supply system is therefore intended to stimulate private fertilizer market development by both increasing aggregate demand for fertilizer and improving links between rural farmers and input suppliers (ibid, 2007).

A second key feature of a 'smart' subsidy program is for them to be targeted to a specific sub-population of households that live in areas where fertilizer use on a staple crop such as maize or rice should be profitable, yet who are known or assumed to have had limited prior access to fertilizer due to resource constraints. Thus, a key assumption behind a truly 'smart' subsidy scheme is that in the absence of targeted subsidies, these 'resource-poor' smallholders lack sufficient physical access to and/or experience with applying fertilizer to staple crops. A second assumption is that by subsidizing these inputs (ideally for a pre-announced and fixed period of time), this will reduce farmers' risk of experimentation and learning regarding the profitability of fertilizer use on a staple crop under their own farm conditions, while providing sufficient aggregate fertilizer demand for private sector retailers to invest in distribution systems.

Based on these considerations, the recent wave of targeted subsidy programs in Africa have arguably been more attentive to minimizing 'crowding out' or 'displacement' of existing smallholder demand for commercial fertilizer (Ricker-Gilbert et al, 2011) and thereby maximize program efficiency in raising smallholder total fertilizer use. While many of the new programs in SSA use vouchers and/or are asserted to be 'smart' by implementers, the extent to which they actually have characteristics of truly 'smart' programs as defined by Morris et al (2007) in design and/or in practice varies considerably (Wanzala et al, 2013). There are thus several compelling reasons why empirical studies of the efficacy and efficiency of these new programs in practice are warranted. First, there are only a few existing rigorous empirical assessments (discussed in more detail below) of the effect of these programs on total smallholder fertilizer use. Second, because the implementation modalities of these so-called 'smart' programs are in fact quite variable in practice across countries, there is still much to learn about how program efficiency and effectiveness varies by the extent to which programs actually adhere to 'smart'

[2] While Ricker-Gilbert, Jayne, and Chirwa (2011) were the first to investigate crowding-in/out of agricultural input subsidies, Cutler and Gruber (1996) noted and tested for crowding-out effects of subsidies in insurance markets.

design principles in practice. Third, little is known to date regarding how well such programs work under differing levels of agro-ecological potential and private-sector input distribution system development both across and within countries. Fourth, in most of the countries implementing these new input subsidy programs, significant amounts of their agricultural sector funding is being devoted to them and mostly from external sources in the form of grants or loans (Jayne and Rashid, 2013).

Despite the importance of the topic, there are only a few extant studies based on panel household survey data that empirically assess the performance of new large-scale or pilot government-led fertilizer subsidy programs, focusing specifically on the effect of household receipt of subsidized fertilizer on their commercial and total fertilizer demand. For example, studies from Zambia (Xu et al, 2009; Mason and Jayne, 2013), Malawi (Ricker-Gilbert et al, 2011), and Kenya (Mather and Jayne, 2015) have found evidence of minimal to substantial levels of crowding out of commercial fertilizer demand. A common finding across these studies is that the extent of crowding-out or displacement is often related to the recipient household's fertilizer demand prior to the subsidy. Thus, crowding-out tends to be larger among households with relatively more landholding and/or asset wealth (Ricker-Gilbert et al, 2011; Mason and Jayne, 2013; Mather and Jayne, 2015) and in areas in which the private sector input distribution system is already well-developed (Xu et al, 2009). By contrast, in poorer areas where private sector input distribution is relatively inactive, Xu et al. (2009) found that subsidies helped to generate and thus 'crowd-in' demand for commercial fertilizer in those areas. Likewise, Liverpool-Tasie (2014) found evidence of crowding-in of commercial fertilizer demand in a pilot subsidy scheme in one district of Nigeria, the success of which appears to be due to the fact that fertilizer vouchers were predominantly targeted to areas where private commercial markets were relatively weak and to households that were relatively poor. These types of empirical findings provide useful information on why the effects of subsidy programs may vary and how the performance of existing (or new) fertilizer voucher programs can be potentially improved through modifications to program design and/or targeting criteria.

There are several reasons why an assessment of the extent to which NAIVS vouchers crowded in/out commercial fertilizer demand is of great value. First, because NAIVS accounted for more than a third of the total budget for the Ministry of Agriculture, Food Security, and Cooperatives (MAFC) between 2009 and 2014, evaluation of the program's effectiveness and efficiency is needed to help guide GoT in their continued pursuit of the underlying goal of improving smallholder household food security and incomes via improvements in smallholder maize and rice productivity. Second, evaluation of the performance of NAIVS may also have important design and implementation lessons for other African countries, given that NAIVS is considered to be the most private-sector friendly of the various large-scale input subsidy schemes recently implemented (between 2000 and 2014) in countries such as Ghana, Kenya, Malawi, Nigeria, Rwanda, and Zambia (Wanzala et al, 2013).

Among existing studies that have evaluated NAIVS, there are two general categories: the first group of studies assess aspects of the program's performance relative to its intended design and implementation plan (Pan and Christiaensen; 2012; Malinza and Chingonikaya, 2013;

Malhotra, 2013; Aloyce, Gabagambi, and Hella, 2014; Mwaijande, 2014; World Bank, 2014). The second group quantifies the household-level impact of voucher receipt by comparing maize (paddy) yields of voucher recipients and non-recipients (Mwaijande, 2014; World Bank, 2014), and then proceeds to estimate an economic rate of return of the program (World Bank, 2014). However, none of the existing studies have used nationally-representative data to specifically assess whether or not household receipt of a voucher led to crowding in or out of smallholder commercial fertilizer demand. In addition, none of these studies have used this data to estimate whether or not significant quantities of vouchers were either leaked or diverted from originally intended recipients.

This paper uses descriptive and econometric analysis of panel household survey data to address four main research questions related to the performance of NAIVS from 2008/09 to 2012/13: (i) To what extent is subsidized fertilizer targeted to smallholder households that meet each program's targeting criteria; (ii) How does household receipt of subsidized fertilizer affect the quantity of commercial fertilizer they purchase as well as their total fertilizer use; and (iii) To what extent do estimates of the marginal effects of subsidized fertilizer on commercial fertilizer demand vary by program targeting criteria, namely agro-ecological zone and total household landholding or asset wealth; (iv) is there evidence of significant leakage or diversion of subsidized fertilizer away from intended recipients? To address these questions, we use panel household survey data from n=1,346 smallholders from all regions of Tanzania that were interviewed in 2008/09, 2010/11 and 2012/13. This household-level data provides a natural experiment for measuring the effects of the NAIVS on smallholder commercial fertilizer demand.

The paper is organized as follows. Section 2 provides a brief review of recent trends in the fertilizer subsector in Tanzania and background on the re-emergence of government-led input subsidy programs. Section 3 describes the data used for our analysis, and Section 4 presents the conceptual framework used to investigate the effects of subsidy receipt on smallholder's commercial fertilizer demand. Section 5 describes our empirical models and estimation strategy, and Section 6 presents our results. Section 7 provides conclusions and policy implications.

2. Background on the reintroduction of government-led input subsidy programs in Tanzania

2.1 Fertilizer policy and smallholder fertilizer use in Tanzania prior to NAIVS

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 effectively first received the subsidy (distributors and/or agro-dealers) would pass on the savings to farmers.

In the year prior to NAIVS, only 12.9% of smallholder maize growers applied 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 23.3% 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.

Table 1. Smallholder use of inorganic fertilizer in maize/rice production by zone, 2007/08

	Among growers of following crop, % smallholders that applied inorganic fertilizer to that crop in 2007/08 main season:	
Zone	maize	paddy
S.Highlands	21.1	5.6
North	13.1	22.9
Eastern	4.3	7.6
Central	1.2	0.0
Lake	1.1	11.4
Western	3.0	0.4
South	42.1	25.9
Total	12.9	7.7

Source: 2007/08 Agricultural Census. 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.

2.2 The National Agricultural Input Voucher Scheme (NAIVS)

Beginning in 2007/08, the GoT decided to continue with fertilizer subsidies, but they shifted the program modality to modifying the targeted voucher approach used in Malawi. For example, in Malawi, a government parastatal physically handled fertilizer from the port to parastatal distribution depots throughout the country. By contrast, in Tanzania, the government role was limited to distributing vouchers to villages/smallholders, and the private sector handled fertilizer intended for the subsidy program from importation all the way to the village level.

In early 2009, although international maize prices had fallen somewhat from their peak in 2008, domestic and regional maize prices remained quite high, in part due to poor short season production in Tanzania and Kenya at the end of 2008. In response, the GoT approached the World Bank and requested financial support in order to dramatically scale-up the existing GoT targeted voucher program. In 2008/09, the GoT, with support from the World Bank, rapidly scaled up their pilot targeted agricultural input voucher program, in order to 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). NAIVS had three 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 long-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 both 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.

Subsequently, the targeting criteria for smallholder voucher recipients was developed with the goal of building smallholder demand for market-priced fertilizer (in the longer-term, after subsidies were eventually phased out). Thus, the initial district-level targeting criteria was to only target vouchers to areas of medium to high potential where fertilizer use on maize/rice was expected to be profitable. There were three main household-level criteria for eligibility for voucher receipt:

1) The ability and willingness to afford the 'top-up' for the allowable quantity of subsidized fertilizer – i.e. upon redeeming the voucher at or before planting, the recipient needed to be willing and able to pay 50% of the market rate of the fixed quantity of subsidized fertilizer.
2) Grow one hectare or less of maize or rice;
3) Household has not have used fertilizer on maize (rice) within the past five years.

Thus, the NAIVS household-level targeting criteria was not specifically intended to reach the 'poorest of the poor' as households unable to pay 50% of the market price of fertilizer would not likely be able to afford fertilizer and/or improved seed once subsidies were phased out. On other hand, program designers did not want subsidized fertilizer to displace or 'crowd-out' existing demand for commercially-priced fertilizer. Thus, recipients had to also meet the second two criteria, which were intended to ensure that vouchers did not go to farmers who were already capable of self-financing fertilizer for use on maize/rice, which tend to be smallholders with larger farm sizes, access to fertilizer via interlinked credit (such as via an out-grower cash crop scheme), or sufficient non-farm income to self-finance such inputs at planting.

Voucher recipients obtained a limited quantity of fertilizer (at 50% the market rate) and 10 kg (25 kg) of maize (rice) seed at 100% subsidy by taking the voucher to a private sector agro-dealer (participating in the program) and paying the 'top-up' amount. This amount of fertilizer and seed was intended to be sufficient (optimal) for use on one acre of maize/rice, and agro-dealers were trained to recommend the subsidy package of fertilizer and seed be applied to only one acre. Each recipient household was intended to receive these vouchers for three years, after which, the initial group of targeted farmers were expected to 'graduate' from the program with enough experience and income to continue to purchase fresh seed and fertilizer on their own (and in subsequent years, eligible farmers who had not yet received three years of vouchers would then begin to receive them).

NAIVS vouchers were distributed each year via a multi-stage targeting process. First, a national voucher committee consisting of officials from the Ministry of Agriculture, Food Security and Cooperatives (MAFC) as well as representatives from regional governments, private sector fertilizer/seed supply chains, and other non-state actors would meet to decide how much subsidized fertilizer to allocate by region each year. At the regional (district) level, government officials decided how many vouchers to distribute to each district (ward). At the village level, a village voucher committee consisting of elected village leaders, a number of resident farmers, and the extension agent serving the village would then assess which households met the eligibility criteria. From among eligible households, the committee then distributed vouchers to eligible households willing and able to pay the 50% top-up fee for two 50 kg bags of fertilizer.

In 2007/08, the GoT pilot voucher scheme targeted two districts. In 2008/09, NAIVS scaled-up rapidly 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, 2014). When NAIVS started, it only targeted areas where agro-ecological potential and prior zonal station research trial data indicated that fertilizer use on maize/rice should be profitable at market rates (i.e. high potential maize zones including the southern highlands, northern highlands, and western regions; high potential rice production areas with irrigation schemes, in areas like Morogoro region, the southern highlands, and a few areas in the Lake zone). However, within two years of the beginning of NAIVS, Members of Parliament (MPs) in districts/regions not targeted by NAIVS pressured the GoT to expand the program to include additional zones, for which maize/rice production is marginal on average. In practice, while the bulk of the vouchers continued to go to higher potential zones, areas with irrigation in lower-potential zones such as the drier central regions of Dodoma and Singida began to receive vouchers for maize and/or rice production.

3. DATA

2.1 Household-level data

In this paper, we used household survey data from two main sources. The first is the National Panel Survey, also implemented by NBS, which 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 it 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 household (5.5%) were re-interviewed in the third wave but not the second.

The second source of household survey data is from a World Bank/REPOA survey of rural households in 2011 (covering the 2009/10 main and short seasons) and 2012 (covering the 2010/11 main and short seasons). The household level surveys interviewed n=2,000 households in 2011 and 2,040 households in 2012, all from villages that had been targeted by NAIVS.[3] Although this sample is not based on population-based sampling, it covers 200 villages from 10 districts in 9 of the regions that received the bulk of NAIVS vouchers from 2008/09 through 2010/11. These regions are located in three agro-ecological zones: the southern highlands, northern highlands and west (Kigoma).

3.2 Village-level data

Distance to 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 are generated by matching the village coordinates to secondary geospatial data.

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 subsidy receipt on household commercial fertilizer demand, we follow the approach of Ricker-Gilbert et al (2011) and 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 Kenya. We assume that a representative farm household in Kenya 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

[3] The survey sample took advantage of the fact that more households were eligible for vouchers than actually received them, thus in every village, an equal number of eligible recipients and non-recipients were interviewed. In each village, REPOA interviewed a random sample of households that were eligible to receive a NAIVS voucher, though purposively selected an equal number of actual voucher recipients and non-recipients (thus the non-recipients serve as a counter-factual group for at least some kinds of analyses).

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) $QFert_c = f(QFert_s, P_f, P_o, T, C, A, Z)$

where $QFert_C$ represents the quantity of commercially priced fertilizer that a household purchases, $QFert_S$ 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 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) $QFert_{cit} = \beta X_{it} + \delta QFert_{sit} + \varepsilon_{it}$

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

$QFert_{cit}$ refers to the quantity of commercially priced fertilizer purchased 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 parameter of interest in (2) is δ the marginal effect of the quantity subsidized fertilizer received on household commercial fertilizer demand. Xu et al. (2009) and Ricker-Gilbert et al. (2011) estimate displacement as the change in the quantity of commercial fertilizer purchased given a one-unit increase in the quantity of government-subsidized fertilizer received by the household. Thus, they estimate the change in total household fertilizer use as one plus the displacement estimate + δ. If + $\delta < 0$ and is significant, this implies that receipt of subsidized fertilizer reduces (crowds-out, displaces) total household commercial fertilizer demand, *ceteris paribus*.[4] By contrast, if $\delta > 0$ and is significant, this

[4] As noted by Mason and Jayne (2013), in the event that there is significant illegal diversion of either vouchers or subsidized fertilizer away from intended villages or depots, then the actual magnitude of effects of household receipt

implies that receipt of subsidized fertilizer increases (crowds-in) total household commercial fertilizer demand.

As noted by Mason and Jayne (2013), in the event that there is either (a) leakage of vouchers such that intended recipients sell rather than use them, and/or (b) significant illegal diversion of vouchers or subsidized fertilizer away from intended villages by government officials, then the actual magnitude of the effect of each kilogram of subsidized fertilizer on total smallholder fertilizer use may need to be adjusted downward. Following Mason and Jayne (2013), after we estimate δ from (2), we then use equation (4) to adjust the unconditional average partial effect of subsidized fertilizer on total smallholder fertilizer use.

$$(4) \quad \frac{\partial total}{\partial govt} = \left(1 + \frac{\partial allcomm}{\partial nonleaked}\right) \cdot \left(1 - \frac{\partial leaked}{\partial govt}\right) = \left(1 + \frac{\partial allcomm}{\partial nonleaked}\right) \cdot \left(\frac{\partial nonleaked}{\partial govt}\right)$$

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[5], expected main season rainfall[6], elevation, household productive assets (total landholding, number of family members age 15-59), household credit access (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 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.

Findings from previous crowding-out studies show that displacement effects tend to be larger for households that are more likely to have purchased fertilizer in the absence of a subsidy – namely, those in areas of higher agro-ecological potential and/or those households with higher wealth levels, as they would be more likely to be able to self-finance such inputs within a

subsidized fertilizer in displacing commercial fertilizer demand may actually be higher than those estimated by our method here.

[5] Binary soil group indicator is from spatial variables provided by the World Bank and matched to the spatial coordinates of each NPS village.

[6] 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.

context of a weak credit market (Xu et al 2009, Ricker-Gilbert et al, 2011, Mason and Jayne, 2013).

In summary, we first use (2) to estimate the average partial effects (APEs) of the quantity of subsidized fertilizer received (from any source) on the household quantity of commercial fertilizer purchased. Given results from this kind of analysis in other countries (CITE), we anticipate that there may be heterogeneity in the APEs of subsidized fertilizer quantity by agro-ecological zone and household characteristics. We therefore also compute APEs of our various subsidized fertilizer quantity variables by agro-ecological zone (one group contains the two low potential zones, the other containing the medium and high potential zones), by household landholding (top and bottom 50% of total landholding), by household farm asset value per AE (top and bottom 50%), and by type of household head (one group containing households headed by a male or married female, the other group containing households headed by a single female). To control for differences in average landholding size by agro-ecological zone, we compute our top/bottom indicators by first ranking sample households by agro-ecological zone.

5.2 Dependent and explanatory variables

Following previous studies (Xu et al 2009; Ricker-Gilbert et al, 2011; Mason and Jayne, 2013; Mather and Jayne, 2015), we define the quantity of subsidized fertilizer received (from any source) in year *t* as the quantity obtained through the voucher (whether via partial or full subsidy). It follows that our definition of the household quantity of commercial fertilizer purchased in year *t* is the quantity the fertilizer that the household purchases at the full commercial price that year. For our econometric analysis, we use a balanced household sample from the 2010/11 and 2012/13 survey waves. We do not use the first wave of the NPS (2008/09) as unfortunately the survey instrument that year only up to one type (and quantity) of inorganic fertilizer applied to a given crop. Because a number of smallholders in the following waves are observed to use more than one type of fertilizer, this implies that the first wave under-estimates actual smallholder fertilizer use in that year.

The quantity of both commercial and subsidized fertilizer is reported by each household. While A recipient of two NAIVS vouchers in principle is expected to redeem each for 50 kg of fertilizer (one bag of basal, one of top-dressing), what we observe in practice is that many households redeem only one voucher, and some appear to be splitting the subsidized fertilizer with other households. For example, although most households (67%) reported receipt of either 50 kg or 100 kg of subsidized fertilizer, the remaining non-zero quantities of subsidized fertilizer range from 10kg to 300kg.

The fertilizer price used in our model is 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.[7]

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

We also include as controls the expected output prices for the two crops targeted by NAIVS vouchers – maize and rice—and four others six crops that are both widely grown and on which Tanzanian smallholders most often apply inorganic fertilizer (relative to other crops). These include Irish potato, tobacco, coffee and sugarcane. Because crop 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, 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 many crops, including several interest to us (maize, rice, Irish potato), we develop a naïve price expectation for each crop 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.[8] 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. Due to data limitations, our post-harvest price expectations for the other crops (tobacco, coffee) are the actual prices observed in NPS survey data each year. While these are not technically expected prices, farmers who grow these crops typically do so as part of an out-grower scheme in which they are in fact given 'indicative' season prices at planting.

Given that nearly all smallholder maize production in Tanzania is rainfed, we include a village-level measure of expected cumulative main season rainfall[9]. 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 that =1 for villages that have 'moderate' or 'severe' soil nutrient retention problems, as well as village-level information on elevation.[10] Finally, we include binary indicators for the years represented by survey wave of 2012/13 to control for the average effect of unobserved factors.

5.3 Modeling a Corner Solution Dependent Variable

An econometric concern for modeling commercial fertilizer demand in Tanzania is the fact that not all farm households apply fertilizer to maize or other crops, thus the household fertilizer demand of non-users is zero. If the distribution of such a dependent variable exhibits a reasonably large number of cases lumped at zero (as in this case), this can create problems for standard OLS regression. We approach the statistical challenge posed by observations of zero

[8] 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.

[9] 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.

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

fertilizer demand not as a missing data problem (which is typically modeled using a variant of the Heckman two-step approach, as in Goetz (1992)), but rather as a corner solution. The rationale for a corner solution model in this case is that a fertilizer demand value of zero is a valid economic choice to be explained, not a reflection of missing data.[11]

The standard approach to modeling a corner solution dependent variable is to use either a Tobit or a double-hurdle (DH) model. When the household's fertilizer use and quantity decisions are made simultaneously, the Tobit model (Tobin, 1958) is appropriate for analyzing the factors affecting the joint decision. The DH model proposed by Cragg (1971) is a more flexible version of the Tobit in that it allows the household decision regarding whether to purchase fertilizer and what quantity to purchase to be determined by different processes. This version of the DH model consists of two stages or hurdles: the first hurdle uses a probit estimator to model the household's decision to purchase commercial fertilizer or not. The second hurdle uses the truncated normal estimator to model the household's decision regarding the quantity of commercial fertilizer to purchase. We use a likelihood ratio (LR) test to determine whether our data is better fit by a Tobit or by a Cragg DH.[12] Once we find that a Cragg fits the data better than a tobit, we next use a Vuong test to determine if the truncated normal is a better fit for the second stage than a lognormal. We find that the truncated normal is a significantly better fit than the lognormal.

To facilitate interpretation of the results from the non-linear models such as Tobit and the DH, 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. Estimating the Cragg DH requires the additional assumption that there is no correlation between the error terms for each of the two hurdles, conditional on the explanatory variables.[13]

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 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

[11] The fact that a NAIVS voucher was intended to provide a recipient household with a total of 100 kg of subsidized fertilizer suggests that this variable may be more appropriately modeled using a Probit rather than a Tobit. In practice, however, a number of the vouchers appear to have been shared by more than one household, as we find that although most households reported receipt of either 50 kg or 100 kg of subsidized fertilizer (about 67% of cases), the rest of the non-zero quantities from NAAIVS ranged from 10kg to 300kg.

[12] The LR statistic comparing the two models is 668,663, the p-value for which is 0.000, which indicates that the Cragg DH model of household commercial fertilizer demand clearly fits our data better than the Tobit in this case.

[13] Ricker-Gilbert et al (2011) note studies that have relaxed this assumption in the DH model, and which have found that their results are similar whether this assumption is relaxed or maintained (Jones 1992; Garcia and Labeaga 1996). We maintain this assumption as well.

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 Tobit and Probit estimators have been shown to be inconsistent (Wooldridge 2002), while the FE truncated normal estimator has been shown to be biased when T<5 (Greene 2004).

We estimate each of the Tobit and double-hurdle models 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. Although we are only using the latter two survey waves due to data limitations regarding quantity of commercial fertilizer purchased in the first wave, we can still benefit from adding three-year time-averages of all time-varying regressors in to the double-hurdle model of commercial fertilizer demand[14].

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 estimate of the partial effect of subsidized fertilizer on commercial fertilizer demand 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 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.[15]

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. Several recent studies have used measures of electoral outcomes in their analysis (Banful, 2011) or as an IV for household receipt of subsidized fertilizer (Mason and

[14] Personal communication with Jeff Wooldridge in 2011.
[15] See Ricker-Gilbert, Jayne, and Chirwa (2011) for a recent application of this adapted control function approach.

Jayne, 2013; Mather and Jayne 2015). Following these studies, the IV we use is "constituency-level electoral threat", which is defined by Chang (2005) as the proportion of votes for the runner-up divided by the proportion of votes for the presidential winner in 2005. Because we are separately controlling for factors typically correlated with fertilizer demand 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=1,487 households from the 2010/11 and 2012/13 survey waves (with n=2,798 observations). The results of our regression-based attrition test find that the binary indicator of attrition is insignificant in the probit (p=0.743) and truncated normal (p=0.931) stages of the DH model.[16] We thus proceed with descriptive and econometric analysis using sampling weights from 2008/09.

[16] If we run the regression-based attrition test using households from a balanced panel instead, we also fail to find attrition in the probit (p=0.228) and truncated normal (p=0.778) stages of the double-hurdle model.

6. RESULTS

6.1 Descriptive analysis of characteristics of recipients of subsidized fertilizer

6.1.1 Regional targeting of vouchers

In this section, we use descriptive analysis of the NPS household survey data from the three survey waves to evaluate the characteristics of households that received NAIVS vouchers, as compared with those that did not. Our aim is to first assess the extent to which the targeting criteria of the NAIVS voucher program was followed in practice. The first targeting criterion of NAIVS vouchers was to distribute most of them to the higher potential regions such as in the southern highlands and northern zones (World Bank, 2014). The NPS data show that household use of subsidized fertilizer on maize or rice was considerably more prevalent in the higher potential southern highlands and northern zones (Table 2). In addition, the NPS data show that nearly all subsidized fertilizer was used on maize and rice, which is what we would expect to see given that NAIVS targeted these crops (Table 2). Overall, NPS data show that 1.1% (1.2%) of rural households used subsidized fertilizer in 2008/09 on maize/rice (any crop), this increased to 7.5% of households in 2010/11 and then fell to 4.9% in 2012/13 (Table 2). The relative change in the percentage of households receiving subsidized fertilizer over time seen in the NPS data is consistent with the fact that the program size was quite small in the first year (2008/09), was at its largest in 2010/11, and then had scaled down somewhat by 2012/13 (World Bank, 2014).

Table 2. Percentage of rural households that reported use of subsidized fertilizer by year

	% of HHs that reported use of subsidized fertilizer (maize or rice)			% of HHs that reported use of subsidized fertilizer (any crop)		
Zone	2008/09	2010/11	2012/13	2008/09	2010/11	2012/13
S.Highlands	4.2	27.9	15.5	4.5	28.4	15.9
North	1.2	8.1	6.8	1.2	8.1	6.8
Eastern	0.0	0.0	0.8	0.0	0.0	0.8
Central	0.0	1.8	0.0	0.0	2.7	0.6
Lake	0.0	0.0	0.0	0.0	0.4	0.0
Western	0.7	3.8	4.0	0.7	5.3	4.7
South	0.0	0.0	0.9	0.0	1.0	0.9
Total	1.1	7.5	4.9	1.2	8.0	5.1

Source: NPS household survey 2008/09, 2010/11, 2012/13, main season

6.1.2 Percentage of fertilizer voucher recipients who redeem voucher for subsidized fertilizer

While Table 2 shows us the percentage of households that reported use of subsidized fertilizer by year, the 2008/09 and 2012/13 NPS instruments record both whether a household reported receipt of a voucher and whether they redeemed it or not. The NPS data shows that 62.8% (78.6%) of households that received a fertilizer voucher in 2008/09 (2012/13) redeemed it for fertilizer, though this percentage varied by region (Table 3). The increase over time in voucher redemption is consistent with key informants from four regions[17] who noted that in the first year or so of NAIVS, some voucher recipients were hesitant to pay the top-up fee and use fertilizer in maize or rice production, as they simply did not know enough about the potential returns to take the risk.

Table 3. Percentage of rural households that received and redeemed a NAIVS voucher for subsidized fertilizer by year (main season)

	Among HHs that received fertilizer voucher, what % redeemed it for subsidized fertilizer	
Zone	2008/09	2012/13
S.Highlands	81.2	82.5
North	37.0	67.9
Other zones	50.0	47.2
Total	62.8	74.5

Source: NPS household survey 2008/09, 2012/13, main season

It is not clear from recipients' responses what households that did not redeem the fertilizer vouchers they received did with them. However, key informant interviews in 2014 with agro-dealers, village leaders and extension agents in four regions targeted by NAIVS (Mather et al, 2016a) suggest several explanations. For example, some voucher recipients did not redeem vouchers as they could not afford the top-up fee, while other recipients reportedly signed their voucher, paid the top-up fee, but then sold the fertilizer either to another farmer or back to the agro-dealer (presumably for cash). Regardless of what voucher recipients did with the voucher they received, the NPS data suggests that there was considerable 'leakage' of subsidized fertilizer at the village level even as late as 2012/13, as 25.5% of recipients of a fertilizer voucher in that year did not redeem the voucher and apply subsidized fertilizer to their maize or rice fields (Table 3).

As noted above, one of the main goals of NAIVS was to provide a relatively lower-risk opportunity for smallholder farmers unfamiliar with applying inorganic fertilizer to maize or rice to do so on one acre of maize or rice. The leakage noted in Table 3 implies that, depending on the year, between 25 to 37% of fertilizer voucher recipients did not apply subsidized fertilizer to their maize/rice production, and thus did not gain that experience. While a household that sold their subsidized fertilizer to another farmer obviously benefited from the voucher (i.e. by receiving cash or some other payment in-kind), the household did not gain the experience with fertilizer use in maize/rice production that was intended. In addition, if the household sold their subsidized fertilizer, it is likely that they would sell it at something close to the market price. In this case, each bag of "leaked" subsidized fertilizer would not lead to an increase in

[17] Based on key informant interviews of agro-dealers, village leaders and extension agents in four regions targeted by NAIVS (Mather et al, 2016a).

total fertilizer use in the village (and in aggregate across the districts) in the event that it displaced fertilizer that would have been purchased at the market price in the absence of NAIVS.

We next consider one of the three main household-level criteria for voucher receipt – that vouchers should go to households planting maize (paddy) but not more than one hectare of it. First, we find that all users of subsidized fertilizer grew maize or paddy. Second, we find that the median area planted to maize (paddy) among households that report use of subsidized fertilizer use in each year is below 1.0 hectares at the national level, and also in nearly all zones each year (Tables 4 & 5).[18]

Table 4. Among households that grew maize that year, median household characteristics by household use of subsidized fertilizer (or not) in that year

	-------- 2008/09 ---------				-------- 2010/11 ---------				-------- 2012/13 ---------			
	HH maize area planted (ha)		HH total land per AE (ha/AE)		HH maize area planted (ha)		HH total land per AE (ha/AE)		HH maize area planted (ha)		HH total land per AE (ha/AE)	
Zone	no[1]	yes[1]	no	yes	no[1]	yes[1]	no	yes	no[1]	yes[1]	no	yes
S.Highlands	0.51	0.77	1.05	1.51	0.52	0.75	1.19	1.14	0.51	0.88	1.15	1.15
North	0.33	0.23	0.70	0.29	0.32	0.26	0.61	0.59	0.24	0.13	0.64	0.54
Eastern	0.40		1.06		0.38		0.95		0.35		1.05	
Central	0.40		1.24		0.39	0.81	1.31	1.20	0.36		1.08	
Lake	0.39		0.83		0.29		0.89		0.24		0.82	
Western	0.65	0.24	1.21	1.00	0.55	1.62	1.21	1.03	0.55	0.71	1.14	1.38
South	0.45		1.27		0.40	0.25	1.44	3.40	0.29	0.73	1.41	7.84
Total	0.44	0.69	1.03	1.34	0.42	0.64	1.08	1.08	0.39	0.64	1.04	1.12

Source: NPS 2008/09, 2010/11, 2012/13, main season. Notes: (1) no (yes) = household did not (did) receive an input subsidy voucher for fertilizer in that year.

Table 5. Among households that grew paddy that year, median household characteristics by household use of subsidized fertilizer (or not) in that year

	-------- 2008/09 ---------				-------- 2010/11 ---------				-------- 2012/13 ---------			
	HH paddy area planted (ha)		HH total land per AE (ha/AE)		HH paddy area planted (ha)		HH total land per AE (ha/AE)		HH paddy area planted (ha)		HH total land per AE (ha/AE)	
Zone	no[1]	yes[1]	no	yes	no[1]	yes[1]	no	yes	no[1]	yes[1]	no	yes
S.Highlands	0.48	0.13	1.16	2.38	0.53	0.73	0.93	1.40	0.40	0.89	1.28	1.07
North	0.33	0.87	0.41	0.48	0.40	0.71	0.32	0.85	0.70	2.70	0.59	0.18
Eastern	0.33		1.14		0.26		0.86		0.36	0.97	1.09	0.37
Total	0.39	0.13	1.11	2.38	0.35	0.73	0.92	1.21	0.39	0.89	1.10	0.95

Source: NPS 2008/09, 2010/11, 2012/13, main season. Notes: (1) no (yes) = household did not (did) receive an input subsidy voucher for fertilizer in that year.

[18] The general finding that median maize (paddy) area planted among recipients is below 1.0 hectares still holds if we instead consider the larger sample of voucher recipients (whether they redeemed it or not) in 2008/09 and 2012/13, as opposed to households that reported use of subsidized fertilizer.

As noted above, NAIVS was not intended to subsidize the poorest-of-the-poor, which perhaps is why subsidy recipients report higher median area planted to maize (paddy) relative to non-recipients. However, in the southern highlands zone – and at the national level in the largest year of NAIVS in 2010/11 – we also find that the median farm size per AE of recipients that grew maize is not larger than that of non-recipients. This suggests that the targeting criteria intended to prevent voucher distribution to considerably larger farmers appears to have been implemented in practice in most cases.

Another key criteria for voucher receipt was to target smallholders who had previously not been using fertilizer on maize (paddy) and/or improved maize (paddy) seed varieties. While the NPS did not ask farmers who received a voucher if they had purchased commercial fertilizer prior to NAIVS, a World Bank survey in 2011 that covered all the main regions targeted by NAIVS did ask this question. This data shows that in 2009/10, 75% of households that had received a voucher in 2008/09 or 2009/10 and who were growing maize in the 2009/10 main season had not used improved seed in the 5 years prior to the beginning of NAIVS (Table 6). Likewise, 60.7% had not used inorganic fertilizer in the 5 years prior to the beginning of NAIVS.

Table 6. Percentage of NAIVS voucher recipients that grew maize in 2009/10 but had not obtained inorganic fertilizer or improved seed in 2008/09 or within the last five years

	% of voucher recipients growing maize in 2009/10 who:			
Zone	**Did not use** inorganic fertilizer (on any crop) during:		**Did not use** improved seed (on any crop) during:	
	2008/09	5 years prior	2008/09	5 years prior
S.Highlands	80.9	86.0	89.7	89.7
North	51.5	61.8	46.0	34.3
Morogoro	93.7	89.3	93.7	89.3
Kigoma	86.1	94.4	86.1	75.0
Total	69.6	75.5	68.5	60.7

Source: World Bank/REPOA household survey, 2009/11

Because the survey question asking about fertilizer use in the five years prior to NAIVS was not crop specific, it is likely that the reason that most smallholders in the northern regions reported use of fertilizer prior to NAIVS is because many of these households use fertilizer on horticultural crops. Nevertheless, the evidence from this survey strongly suggests that the NAIVS targeting criteria were largely implemented in practice (especially in the main maize growing regions of the southern highlands), as most voucher recipients had not used improved seed or inorganic fertilizer – at least not in the 5 years prior to NAIVS. With respect to paddy, 87% (90%) of voucher recipients in the World Bank/NAIVS household survey had not used inorganic fertilizer (improved seed) in paddy production in the 5 years prior to NAIVS (Table 7).

In summary, the descriptive evidence from NPS and World Bank household survey data suggests that the majority of NAIVS voucher recipients met the three key intended targeting criteria as noted above.

Table 7. Percentage of NAIVS voucher recipients that grew paddy in 2009/10 but had not obtained inorganic fertilizer or improved seed in 2008/09 or within the last five years

	% of voucher recipients growing paddy in 2009/10 who:			
	Did not use inorganic fertilizer (on any crop) during:		**Did not use** improved seed (on any crop) during:	
Zone / region	2008/09	5 years prior	2008/09	5 years prior
S.Highlands	87.0	89.1	87.0	89.1
Northern	65.7	51.4	65.7	51.4
Morogoro	96.9	94.4	96.9	94.4
Kigoma	0.0	100.0	0.0	100.0
Total	90.1	87.2	90.1	87.2

Source: World Bank/REPOA household survey, 2009/11

6.3 Econometric Analysis

6.3.1 Determinants of household receipt of subsidized fertilizer

Table 8 presents results from a reduced form Tobit model of the quantity of subsidized fertilizer received by the household. The IV "electoral threat" is significant and positive at the 10% level (p= 0.052), lending credibility to its validity as an IV. We do not have an expectation about the sign of this variable *a priori.* However, the negative sign suggests that, holding other factors constant, less subsidized fertilizer was distributed to constituencies where the runner-up did relatively well in the 2005 Presidential election.

Table 8. Reduced form Tobit regression of factors affecting household quantity of subsidized fertilizer obtained, 2010/11, 2012/13

	Tobit-CRE	
	Dep variable = HH quantity of subsidized fertilizer obtained	
Explanatory variable	**APE**	**p-value**
Year dummy (1=2013)	-4.341	0.031
ln(Expected main season rainfall (mm))	2.377	0.515
Elevation - meters above sea level	0.001	0.189
1=soils with poor nutrient retention	3.244	0.009
real price of urea	0.012	0.025
real exp price of maize (Jul-Sep) (Tsh/Kg)	-0.001	0.916
real exp price of irish potato (Jul-Sep)	0.002	0.837
real exp price of tobacco	0.000	0.755
real exp price of coffee	0.002	0.368
distance to nearest market (km)	0.043	0.000
distance to nearest road (km)	-0.060	0.016
ln(real farm equipment value)	0.202	0.644
Total landholding size (Ha)	-0.022	0.719
Head's age (years)	0.045	0.173
Maximum education in the HH (years)	0.400	0.087
# of HH members age 15-64	0.093	0.890
Number of children age 0-15	-0.177	0.763
Number of HH members age 65 or above	-4.888	0.018
electoral threat	-10.110	0.052
Number of observations	2,798	
Correlated random effects terms included	yes	
Psuedo R-squared	0.143	

Notes: Model includes binary indicators for agro-ecological zone (5 of 6), squared terms for head's age, and time averages terms for each of the time-varying regressors except for head's age. APE= Average Partial Effect. Survey sampling weights from 2008/09 applied via Stata.

Consistent with our descriptive results above, we find that household total landholding does not have a significant effect on quantity of subsidized fertilizer received (Table 8). The fact that we do not find a significant effect of household total value of farm assets (a proxy for wealth) also suggests that NAIVS vouchers were not predominantly captured by wealthier smallholder households. In addition, the negative sign on the 2012/13 year dummy is consistent with the fact that NAIVS was at its largest in 2010/11 and had scaled down to some extent by 2012/13 (Table 8).

6.3.2 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 'electoral threat'. We then add the endogenous variables and the residuals from the reduced form probit into the two stages of the Cragg DH model. We find that control function tobit residual is not significant in the probit (p=0.304) or truncated normal (p=0.251) stages of the model, nor as an unconditional quantity effect (p=0.913). Thus, we conclude that household quantity of subsidized fertilizer is exogenous, and we do not leave the control function residual in the DH model.

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

Due to space limitations, the estimation results of our DH model do not include the APEs for some of our explanatory variables (Table 9), however, the joint significance of these variable groups in the probit stage of the DH[19] is quite strong. We maintain them in both stages based on their merit on conceptual/theoretical grounds, on their strong significance in the first stage (which together with coefficients from the second stage are used to compute unconditional quantity effects), and because it is generally preferable to use the same set of explanatory factors in both stages where possible (Wooldridge, personal communication).

Our control for elevation has the expected the expected positive and significant effect on both probability of commercial fertilizer purchase and quantity of commercial fertilizer purchased, conditional on purchase (Table 9) (i.e. the "conditional quantity purchased"). Our control for expected rainfall has the expected positive and significant effect on probability of commercial fertilizer purchased, but an unexpectedly negative (though insignificant) effect on conditional quantity purchased.

[19] The joint significance of the agro-zone dummies is p=0.000 in the probit stage and p=0.6708 in the truncated normal stage.

Table 9. Cragg double-hurdle regression of smallholder quantity of commercial fertilizer purchased, 2010/11, 2012/13

	Probit		Truncated Normal		Probit + Trunc Normal	
	Dep variable = 1 if HH purchases commercial fertilizer for maize		Dep var = HH qty com. fertilizer applied to maize (kg), growers only (conditional)		Dep var = HH qty com. fertilizer applied to maize (kg), all HHs (unconditional)	
Explanatory variable	APE	Pvalue	APE	Pvalue	APE	Pvalue
Year dummy (1=2013)	-0.0431	0.0277	188.225	0.218	12.700	0.357
ln(Expected rainfall in wettest quarter (mm))	0.1352	0.0036	-111.574	0.513	2.795	0.982
Elevation - meters above sea level	0.0000	0.0104	0.077	0.092	0.016	0.744
1=soils with poor nutrient retention	0.0002	0.9915	-34.730	0.231	-3.767	0.504
HH qty of subsidized fertilizer received (kg)	0.0008	0.0000	0.128	0.598	0.109	0.000
real price of urea	0.0001	0.0404	-0.063	0.615	0.009	0.004
real exp price of maize (Jul-Sep) (Tsh/Kg)	0.0003	0.1620	-0.115	0.800	0.019	0.026
real exp price of irish potato (Jul-Sep)	0.0003	0.0375	-0.298	0.583	-0.004	0.476
real exp price of tobacco	0.0000	0.6892	0.070	0.082	0.008	0.000
real exp price of coffee	0.0001	0.0116	-0.105	0.559	-0.002	0.415
distance to nearest market (km)	0.0005	0.0002	0.570	0.052	0.132	0.000
distance to nearest road (km)	-0.0017	0.0000	1.386	0.141	-0.036	0.148
ln(real farm equipment value)	-0.0032	0.3895	14.263	0.157	1.370	0.000
Total landholding size (Ha)	0.0004	0.5433	3.436	0.096	0.468	0.000
Head's age (years)	-0.0007	0.1852	-0.377	0.781	-0.110	0.590
Maximum education in the HH (years)	0.0021	0.5495	6.616	0.573	1.110	0.000
# of HH members age 15-64	-0.0043	0.6654	-29.973	0.029	-4.305	0.000
Number of children age 0-15	-0.0025	0.7782	-36.916	0.021	-4.907	0.000
Number of HH members age 65 or above	-0.0374	0.1466	-65.814	0.469	-13.009	0.000
Number of observations	2,798		311		2,798	

Notes: Model includes dummies for agro-ecological zone (5 of 6), squared terms for head's age, & time averages terms for each of the time-varying regressors.
APE= Average Partial Effect. Survey sampling weights applied.

The real price of urea has the expected negative sign on conditional quantity purchased, yet the effect is insignificant and it has an unexpectedly positive and significant effect on the probability of purchase (Table 9). The output price variables each have the expected positive sign in the probit stage, and the real price of Irish potato and coffee have a significant effect, while that for maize is not far from significant (p=0.16). The prices of maize and coffee have a significant and positive effect on unconditional quantities purchased. The prices of maize, Irish potato and coffee have an unexpected negative sign on conditional quantities purchased, though these effects are not significant.

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 9). We unexpectedly find that the effect of distance to road is unexpectedly 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. In addition, sales of fertilizer-using crops like tobacco and coffee are not made in traditional markets.

Given that credit for agricultural inputs in rural Tanzania faces extremely high interest rates, the only fertilizer obtained on credit is typically from interlinked credit via a cash crop out-grower scheme. Given this context, it is not surprising that the signs of the effects of total household landholding and asset wealth are positive on conditional and unconditional quantities purchased, and that these effects are significant for unconditional quantities purchased (Table 9).

<u>6.5.3. APE of subsidized fertilizer on household commercial fertilizer demand</u>

We have three main findings related to the effect of household receipt of subsidized fertilizer on household commercial fertilizer demand. First, we find that receipt of a kilogram of subsidized fertilizer increases the probability of commercial fertilizer purchase by 0.08%. This means that receipt of one fertilizer voucher (for 50kg of subsidized fertilizer) would increase the recipient household's probability of purchasing commercial fertilizer by 4.0% (Table 9).

Second, we find that an additional kilogram of subsidized fertilizer received results in a small but positive 0.11 kg increase on the quantity of commercial fertilizer purchased. This suggests that receipt of subsidized fertilizer has a small "crowding-in" effect among recipient households that both received a voucher and chose to use it (instead of sell it). This result is perhaps not that surprising given that other studies have tended to find crowding-in (out) where vouchers were targeted primarily to households that previously did not (did) purchase commercial fertilizer. Nevertheless, this is an important finding considering that most other studies to date of large-scale subsidy programs have typically found evidence of crowding-out. The simplest explanation for why we do not find crowding out on average from NAIVS is found in Tables 6 & 7 above, in which we find that the majority of subsidy recipients had not previously used fertilizer on maize or rice. By contrast, crowding-out in Kenya was found to be quite high because much of the subsidized fertilizer from its two programs was targeted to medium and high potential areas in which 85 to 95% of all rural households were already using large amounts of commercially-priced fertilizer on maize several years before the subsidy programs began (Mather and Jayne, 2015).

The finding of 'crowding-in' implies that each additional kilogram of subsidized fertilizer received by any given household (the 'unconditional quantity effect' from a Cragg double-hurdle) contributes an additional 1.11 kg to that household's total fertilizer use (on average). However, when we adjust the unconditional APE of subsidized fertilizer on commercial fertilizer demand by the fact that a significant portion of subsidized fertilizer was 'leaked' at the village level (i.e. the farmer sold the voucher or the subsidized fertilizer to someone else, as per Table 3 above), this lowers the overall effect of subsidized fertilizer distribution on total smallholder fertilizer use. Thus, our third main finding is that when we adjust the national-level APE in 2012/13 (2008/09) by the fact that approximately 25.5% (37.2%) of subsidized fertilizer delivered to villages was not actually used by the intended recipients, this implies that the adjusted effect of an extra kilogram of subsidized fertilizer on total fertilizer use in 2012/13 (2008/09) was 0.827 kg (0.697 kg) (Table 10). The fact that this number is below 1.0 does not imply that there was crowding-out in that year, simply that, as has been found elsewhere, 'leakage' or 'diversion' of subsidized fertilizer can significantly reduce the efficiency by which subsidized fertilizer increases total smallholder fertilizer use.

Table 10. Estimated kg change in total smallholder fertilizer acquisition given a 1-kg increase in NAIVS fertilizer distributed, by year

	APE of 1 kg subsidized fertilizer on household commercial fertilizer use (kg)	APE of 1 kg subsidized fertilizer on total HH fertilizer use (kg)				
		Un-adjusted APE	Estimated % of NAIVS fertilizer that is leaked[1]		APE adjusted by % fertilizer that is leaked[2]	
			2008/09	2012/13	2008/09	2012/13
Tanzania	0.110	1.110	37.2%	25.5%	0.697	0.827

Notes: 1) derived from Table 3; 2) Adjustment using equation (4) above.

7. CONCLUSIONS

As has been well-documented, during the mid-to-late 2000s, a number of SSA governments (including Ghana, Kenya, Malawi, Nigeria, Rwanda, Tanzania and Zambia) responded to the 2007/08 international food price crisis and the long-standing challenge of low smallholder staple crop productivity by initiating large-scale, government-led fertilizer subsidy programs (or continuing ones started earlier in the 2000s). The publically-stated goal of many of these programs is to induce higher levels of smallholder fertilizer use, which are assumed to lead to improvements in crop productivity and thus higher household incomes and improved food security. However, the degree to which an input subsidy program raises total smallholder fertilizer use depends on the extent to which receipt of subsidized fertilizer crowds-out (or crowds-in) the quantity of commercial fertilizer that a subsidy recipient smallholder theoretically would have purchased at the market rate in the absence of a subsidy (Ricker-

Gilbert, Jayne, and Chirwa 2011). While many of the new programs in SSA use vouchers and/or are asserted to be 'smart' by implementers, the extent to which they actually have characteristics of truly 'smart' programs as defined by Morris et al (2007) in design and/or in practice varies considerably (Wanzala et al, 2013).

When faced with similar challenges to national level food security and the long-standing challenge of low smallholder maize/rice productivity, Tanzania scaled-up an existing pilot targeted voucher scheme in 2008/09 (NAIVS), which ran through 2013/14. Relative to other large-scale programs of its era, on paper, the design of this program represented a considerably 'smarter' and more private-sector friendly approach to a large-scale fertilizer subsidy scheme (ibid, 2013). The initial goal of this program was for the GoT to target input vouchers to households that were neither the poorest of the poor nor wealthy enough to have used fertilizer on maize/rice before, and to have them redeem these participating private sector agro-dealers, and to continue this for a limited time period (4-5 years), so as to help jump-start a market-driven fertilizer/seed supply chain for maize and rice.

This paper uses descriptive and econometric analysis of panel household survey data to assess two main aspects of the performance of NAIVS from 2008/09 to 2012/13: (i) To what extent is subsidized fertilizer targeted to smallholder households that meet each program's targeting criteria; (ii) How does household receipt of subsidized fertilizer affect the quantity of commercial fertilizer they purchase as well as their total fertilizer use? To address these questions, we use panel household survey data from n=1,487 smallholders from all mainland regions of Tanzania that were interviewed in 2008/09, 2010/11 and 2012/13.

We have five main findings. First, we find that the majority of subsidy recipients met the targeting criteria in practice – that is, few of them had used inorganic fertilizer on maize or rice in the previous five years, nor did the median household area cultivated to maize or rice exceed 1 ha. Second, we find that approximately 25.5% (37.2%) of households receiving a voucher for subsidized fertilizer did not use it in 2012/13 (2008/09). One of the main goals of NAIVS was to provide a relatively lower-risk opportunity for smallholder farmers unfamiliar with applying inorganic fertilizer to maize or rice to do so on one acre of maize or rice. While a household that sold their subsidized fertilizer to another farmer obviously benefited from the voucher (i.e. by receiving cash or some other payment in-kind), the household did not gain the experience with fertilizer use in maize/rice production that was intended. In addition, each bag of "leaked" subsidized fertilizer would not likely lead to an increase in total fertilizer use in the village (and in aggregate across the districts) in the event that it displaced fertilizer that would have been purchased at the market price in the absence of NAIVS.

Third, we find that receipt of a kilogram of subsidized fertilizer increases the probability of commercial fertilizer purchase by 0.08%. This means that receipt of one fertilizer voucher (for 50kg of subsidized fertilizer) would increase the recipient household's probability of purchasing commercial fertilizer by 3.5%.

Fourth, we find that an additional kilogram of subsidized fertilizer received results in a small but positive 0.11 kg increase on quantity of commercial fertilizer purchased. This suggests that receipt of subsidized fertilizer has a small "crowding-in" effect among recipient households that both received a voucher and chose to use it (instead of sell it). This implies that NAIVS is the only large-scale fertilizer subsidy program in Sub-Saharan African during the 2008-2014 period that managed to avoid 'crowding-out' of smaller commercial fertilizer demand at a national level, on average.

Fifth, when we adjust the national-level APE in 2012/13 (2008/09) by the fact that approximately 25.5% (37%) of subsidized fertilizer delivered to villages was not actually used by the intended recipients, this implies that the adjusted effect of an extra kilogram of subsidized fertilizer on total fertilizer use in 2012/13 was 0.827 kg (0.697 kg). The fact that this number is below 1.0 does not imply that there was crowding-out in that year, simply that, as has been found elsewhere, 'leakage' or 'diversion' of subsidized fertilizer can significantly reduce the efficiency by which subsidized fertilizer increases total smallholder fertilizer use.

Although NAIVS did exhibit some of the problems seen in other large-scale subsidy schemes elsewhere (late delivery of fertilizer in some areas/years, leakage, etc), these results suggest that when agricultural input subsidy programs are closer to the truly 'smart' criteria of Morris et al (2007) in both design and implementation, they can dramatically reduce the probability of crowding-out of smallholder demand for commercial fertilizer. That said, in recent years, considerably 'smarter' program designs have been implemented, relative to NAIVS. For example, use of e-vouchers in Nigeria should theoretically help to control leakage/diversion. In addition, pre-selection and pre-payment of subsidized fertilizer via an e-voucher in Burundi should both reduce leakage and ensure that farmers can access the type and amount (i.e. smaller bags if desired) of fertilizer desired by each recipient can theoretically bring dramatic reductions in leakage/diversion.

In conclusion, there are two main caveats to the findings in this paper. First, while there is evidence that NAIVS appears to have provided the jump-start/experience period for both farmers and other supply chain actors (Mather et al, 2016a) that the World Bank and MAFC technocrats designed it to be (World Bank, 2009), this does not necessarily imply that continuing a program like NAIVS is the best or only policy option to address Tanzania's challenge to achieve sustainable increases in smallholder food crop productivity in the long-term. For example, recent research demonstrates that smallholder fertilizer use on maize is only marginally profitable (on average) even in higher potential zones, due in large part to low average smallholder maize-N response rates as compared with potential response rates (Mather et al, 2016b). Thus, regardless of whether input subsidies are continued or not by GoT in the future, increased focus and expenditure on complementary strategies are needed to address the long-term challenge of sustainable increases in smallholder maize/paddy productivity (Mather et al, 2016b).

A second caveat is that the finding of no crowding-out in this paper may no longer apply to NAIVS as it is being implemented in 2016/17. The reason for this is because the findings in this paper are based on farmer behavior observed in 2010/11 and 2012/13, yet NAIVS continued to be implemented in 2013/14, 2015/16 and 2016/17. Given that NAIVS has been implemented a total of seven years, if many smallholder farmers have begun to increase their use of commercial fertilizer on maize/rice over that time period, then the prospects for continuing to find no crowding out from NAIVS may diminish over time as the pool of households that can afford the 50% top up fee yet which have also not used commercial fertilizer recently may well become considerably smaller. In other words, the longer that NAIVS is implemented, the more it may become a type of income transfer program as opposed to its original intent of introducing smallholders to fertilizer use on maize/rice.

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